Carving Stone

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Chapter 1

Why This Book?

Artists have been carving the figure in stone for tens of thousands of years, and critics were already pronouncing on it centuries before books were invented. What could possibly be left to say?

A lot, actually. The history of what happened in Western culture over the last violent century would fill a library, and learned authors disagree about nearly all of it, but one thing you can safely say is that the Twentieth Century destroyed and remade just about everything pertaining to sculpture: the subjects, the styles, the media, who made it and for whom, even the meaning of the word itself. Carving in stone has barely begun to be reconciled to these revolutions, and everything about sculpture, from the aesthetics to the mechanics, continues to be in flux.

Figurative carving in the West, already vigorous, flowered in the late Victorian and Edwardian eras, from the 1880's to the outbreak of the First World War. The period has probably never been surpassed, either in terms of sheer technical virtuosity, or in the number of sculptors working[1]. In the last decades of the old order, the ancient traditions were still vibrant, and the burgeoning

[1] The subject tends to get short shrift in histories of this period because, as we look back, the big story of the era seems to be Modernism, which was then gathering steam, and would become the direct forerunner of the visual arts of today. It is easy to lose sight of the fact the Academy was decidedly center stage until well into the Twentieth Century, and Modernism the minor player in all of the plastic arts, but particularly in sculpture. In 1912, at age 31, five years after he had painted *Les Demoiselles d'Avignon*, Picasso's London dealer was still selling his works for between two and twenty English pounds—as little as a workman's weekly pay. The work of Henri Matisse (1869-1954), one of the first artists of that generation to become successful, first entered a public collection in the same year, when his 1910 *Still Life With Geraniums*, was given to the Pinakothek der Moderne in Munich. In contrast, between 1900 and 1920, the paintings of Lawrence Alma-Tadema (1836-1912), the Dutch-English painter of Classical scenes, were routinely sold for up to 6000 pounds—equivalent to half a year's income for the president of a major bank or corporation. Figurative works by prominent scultptors working in the Academic style were also valued in this range. For instance, the first two full–size marble versions of Rodin's *The Kiss* each sold for 20,000 French francs in 1888, and 1900. Comparing money across such a long period of time is complicated, but this would be equivalent to at least twenty years pay for a working man, double that for a working woman, perhaps a million 2013 dollars.

Figure 1.1: Death and the Sculptor, original 1893, carved in 1917, Daniel Chester French, Metropolitan Museum, NY

wealth produced by industrialization, the rapid expansion of state power, and the explosive growth of cites, had created a sustained building boom of unprecedented size. Sculpture was the handmaiden of Beaux-Arts architecture, and across the United States, Europe and the colonies, government buildings, train stations, opera houses, museums, and monuments were decorated with figurative work, giving sculpture a place alongside architecture and painting at the center of the culture of art.

Yet the cultural world of the turn of the century would be swept away within a generation. Behind the gorgeous Beaux Arts facade, the underpinnings of high culture had been eroding for generations. Industrial–age economies and politics had far outgrown rule by hereditary aristocracies, kings, queens, and churches, but the old power structures still persisted, buoyed up by the surging wealth of society as a whole. Tastes in art had long been determined by these powers, primarily through the academies, but throughout the Nineteenth Century, private citizens, members of a growing, educated, and ambitious upper middle class, had increasingly become the tastemakers of a powerful countercurrent of radical new styles. Art in the Grand Manner catered to aristocrats with vast halls to fill, but by the turn of the century, the default perspective of the new art styles was was moving to the personal and oppositional.

The Great War laid waste to ancient power structures across Europe. Of the five empires that entered the war in 1914, only the British Empire would emerge intact. The German, Austro–Hungarian, and Ottoman Empires, were dismembered, and the vast Russian Empire replaced with the a collection of nominal republics under the iron rule of the Russian dictatorship. The cataclysm sapped the grip of even the victorious powers on their colonies, unleashing populist and nationalist movements among the victors and the vanquished alike.

The Communists, in addition to their spectacular success in the former Russian Empire, led a groundswell of popular uprisings in the West, and governments on both sides, answerable as never before to labor movements and an increasingly powerful middle class, were threatened by both leftist and rightist radicals contending for power.

New powers needs new symbols, and the overwhelming dominance of Beaux-Arts architecture was shaken off almost overnight, along with the aristocracies that had supported it. The new architecture of state and economic power no longer sought to legitimize itself through aesthetic appeals to ancient tradition, but glorified the new streamlined industrial age. Since the mid–century, forward–looking painters had already gone far down the road from the Academy, but figurative carving, much more closely tied to architecture, had not, and was largely stranded. Established power did not abandon art patronage immediately or completely, nor did the traditional styles disappear instantly, but the Twentieth Century artist's conception of who he or she was, and who the audience was, changed profoundly during this time. Suddenly, the tide of history was with artists who saw themselves as the vanguard of a cultural revolution.

Painting flourished in this period, responding to the the cultural chaos with an explosion of movements and styles that continues even to the present day, and most of these violently rejected Academic Realism. Much of the new Modernist art was abstract, and the figurative work that remained tended towards expressionism. The size of paintings from this period hints at the cultural change: the works of the Modernists, extending the trend of their extra–Academic predecessors, tended to be on a scale that could be executed by an unassisted individual, and displayed in an apartment or townhouse—no estate or palace required.

But even apart from the tastes of the market, little about full-scale figurative stone sculpture was consistent with the self-image of the Twentieth Century bohemian artist. Painting is inherently avant–garde friendly because paintings are cheap to make[2]. It's an exceptional painting that costs more than one or two day's pay in materials; the painter paints what he or she pleases, and the patron can take it or leave it. But the economics of stone and bronze could hardly be more inimical to the bohemian spirit. Figurative sculpture is not made in a garret—a single piece might take a year or more, and there is a huge up–front cost for materials, equipment, long–term studio space, and assistants. The capital expense, and the severely limited opportunities for placement, usually imply that a commission is required, even for a well–established artist[3]. The

[2] This was to some extent a consequence of technological change. The invention of scores of synthetic pigments, starting in the early Nineteenth Century, made painting cheaper, while simultaneously expanding the palette with vibrant greens, yellows, and blues which had formerly been either unknown or enormously expensive. Many of these new pigments were of unprecedented strength and/or opacity, making it possible to paint alla-prima, what formerly had required patient layering–on over a period of weeks or months. The invention of oil-paint in a tube, in 1841, turned painting, for the first time, into something that could be easily done outside of studio. Tube–paint catalyzed a chain of other inventions, such as the portable easel, aimed at making painting still more portable. Suddenly, painting was an activity that could be done out of a kit the size of a briefcase, indoors or out. See *Revolution in Paint* [Hurt 07].

[3] The usual practice in the late Nineteenth Century, for major pieces that did not have

social dynamic for sculptors was as unpropitious as the economics: the need for a prior commission reverses the canonical Twentieth Century relationship of artist and patron, in that with figurative stone sculpture, it is usually the patron who decides what gets carved, and the sculptor who can take it or leave it. It was the century of the avant–garde, but the figurative realist in stone is almost always working for the man.

By the 1950's the reaction against academic traditions had become so strong, and so institutionalized and entrenched, that countless Beaux Arts structures, especially in England and the United States[4], were wantonly demolished, and the sculpture destroyed or dispersed, and much late 19th Century painting and sculpture consigned to the museum basement. Even in this climate, stone carving, even realistic figurative carving, never completely disappeared, but the styles changed overwhelmingly.

In consequence, many the manual techniques that were commonplace at the end of the Nineteenth Century were no longer interesting enough to make it into the how-to books written a generation or two later; the aesthetic concerns they supported no longer applied, if indeed practicing sculptors remembered them at all. The sculptors who followed the generation of Rodin tended not to come out of the Academy, nor did they aspire to it; they came from the bohemian world, and their works was not subordinated to an architectural canon. Artists of those generations had little reason to know or care about either the aesthetics or the techniques of the Beaux-Arts or the Classical tradition—they were of a new world.

As a result, most of the currently available books on stone carving are not comprehensive, and even the best, e.g., Malvina Hoffman's *Sculpture Inside and Out,* 1939, are significantly out of date, having been written just before the new generation of tools came along. The relatively few sources in print tend to repeat each other, even to the extent of re-using the illustrations from earlier books, and are often factually incorrect even about the basics. Moreover, mid-Twentieth Century authors are often extraordinarily prim about certain issues of technique and composition, taking a curiously moralistic view of practices that were unremarkable when carving was more widely practiced. But times change, and these viewpoints are showing their age. The rebellion against academic traditions in which those antipathies originated is now itself ancient history, as distant from the present as the Napoleonic Wars had been when the influence of the academies collapsed.

The information is all out there—it hasn't been lost—and there are fine sculptors of stone practicing today, as well as many commercial sculptors and art restorers, but figurative carving remains a somewhat specialized area, out-

a prior commission, was to exhibit the piece in plaster first, and execute in either bronze or marble if and when a purchaser was found. But even in plaster, a large piece requires significant direct cost, and stable commercial space.

[4] Demolition of the spectacular Pennsylvania Station in New York, designed by the firm of McKim, Mead, and White, and opened in 1910, was already being proposed in the 1950's, and was finally accomplished in 1963. So little was the style valued, that the massive columns and other decorative elements were not even salvaged, but simply were simply trucked to the NJ Meadowlands and dumped for land fill.

side the mainstream of contemporary art. A few schools still teach academic techniques, and more are coming up, but most artists who are new to carving must scrape the knowledge together from obscure sources, or rediscover it by trial and error. Information on advanced topics is hard to find, for instance, how do sculptors carve the arms and fingers without breaking them off? How do you copy a plaster original into stone, or enlarge a maquette to full size? Why do some carvers work from all sides, and others from front to back? How were the ancient works carved before there were power tools, steel, and tugsten carbide?

The aesthetics of stone carving also have a rich history that remains as relevant as ever to contemporary sculptors, if only as a starting point. Yet in every generation, presentations of these issues are inevitably colored by the current state of the ongoing culture wars—each new generation requires a fresh presentation filtered though the most up–to–date prejudices. Why does the use of mechanical measuring devices arouse furor? Why did generations of artists, critics, and historians obsess over the use and abuse of the drill? Why have artists and critics argued vehemently about the number of viewing positions a sculpture should be composed for: one, two, four, eight, or infinitely many? Why did some of history's greatest sculptors assign bronze and painting to one category, and put carving in a category of its own?

The late Nineteenth and early Twentieth Centuries produced some of the most beautiful figurative stone sculpture in history, yet after a century of aesthetic revolution, Western art is once again nearly as culturally distant from the Classical tradition as it was in the late Middle Ages. It's still all around us, but to most of us it is ancient history, even though the world that made it ended only one long lifetime ago. This book represents an attempt to bring together as much this diverse knowledge as possible for a new generation of artists, critics, and aficionados. Inevitably, there will be omissions, errors, and vehement disagreements. Readers are invited to contribute corrections, opposing views, comments, and suggestions, which will be folded into as appropriate, and gratefully acknowledged.

Chapter 2

Origins

The stone carver's tookit was remarkably stable for much of recorded history. Between the Classical Period of Greece, starting in the mid–Fifth Century BCE, and the late Nineteenth Century, the basic tool kit evolved hardly at all. Only in the last hundred and twenty years, with the introduction of power tools, and ultra–hard materials such as tungsten carbide and carborundum[1], has the sculptor's tool kit expanded significantly beyond what was available to Phydias, during the building of the Parthenon. Even today, more than a century into the era of power tools, while the tool set has been augmented, all but a few of the old tools remain in use. A Twenty-First Century sculptor would be familiar with almost everything in Phydias's tool bag except bow-powered rotary drills and grinders, which have been replaced by power tools that do much the same thing faster, with less effort. The extraordinary stability of the tools and media, and the simplicity of the process, give us a rare chance to look at the aesthetic intentions of each age, without the confounding factor of the available technology.

2.0.1 The Tool Kit

Figure 2.0.1 shows the basic tools of a mid–Fifth Century BCE Greek sculptor. These illustrations are not drawn from ancient Greek artifacts. Although a handful of illustrations of sculptor's tools dating from the period exist, no sculptor's tools from ancient Greece are known to have survived[2]. Instead, most of what is known about the ancient tools is inferred from the the tool-marks on datable sculpture and architecture, and from the known capabilities and limita-

[1] The hand-held pneumatic air hammer for stone carvers was patented in 1888. The first hand–held electric drill was patented in 1895, but was first manufactured in roughly its modern form in 1917. Silicon carbide was invented in 1891, and tungsten carbide tools were introduced in the 1930's. Modern tool steels, as opposed to simple high–carbon steels, is a vaguer category, but most of the important alloys and processes also date from approximately the turn of the century.

[2] Interestingly, much older tools from Fourth Millennium BCE Egypt have been found in ancient tombs. Even the "Copper Age," tools remain very recognizable.

tions of the metallurgy of the various periods. While the sculptor's tools have been lost, weapons and other artifacts from the ancient world are abundant, and give us a very good idea of the metallurgy of the ancient world. There are numerous extant examples of the marks of every kind of tool, and every stage of carving, from uncompleted sculptures, portions of sculpture left rough because they were not intended to be exposed, and from architectural stonework, which required a closely related tool set. While some interesting arguments remain, a great deal of evidence survives to give modern scholars a good idea of what tools existed when.

The tools in use prior to the 20th Century fit into just a few categories:

- Abrasives and scrapers to wear away the surface:
  - Abrasive stones such as pumice, sandstone, sand, and especially emery (corundum) from the Greek island of Naxos.
  - Files, rasps, and scrapers, made of hard stone or steel.
  - Saws for stone. Unlike saws for wood, which make many tiny slicing cuts, ancient saws for stone worked by abrading the stone, and were often made of soft metals that applied pressure to abrasives such as emery or sand.
- Tools that remove stone by pulverizing the surface:
  - Hard stone balls and stone hammers were used on the hardest stones. (This was one of the most important tools for the Egyptians working in granite, basalt, etc., but was not common in Greece, where most work was in stones of middle hardness.)
  - Bush hammers, a.k.a., bouchards, are metal hammers with textured faces, often fields of pyramids similar to those on a meat tenderizer, but occasionally other patterns are used. Sometimes punches and chisels with textured faces are used in this way.
  - Percussion drills, which were iron or steel rods with a cross, star shape, or edge at the end. They were tapped with a hammer, while being twirled with the fingers, in order to wear a hole into the stone.
- Tools that penetrate the stone to split away chips or chunks:
  - Punches, also called point chisels, are metal spikes, usually square, that are driven with a hammer. They are usually used to remove superficial chips but can be used in other ways too.
  - A pick is a hammer with a punch instead of a face. They can be used either to remove superficial chips or to knock off larger chunks, particularly with softer stone.
  - Heavy chisels, trimming hammers, and similar edged tools, which are intended to be driven directly into the stone to split it.

  - Claw chisels which function like a fixed row of punches, to remove stone in a controlled way.

- Edged tools driven with a hammer, or sometimes pushed by hand, at an angle to the stone to shave away, rather than chip away, the stone:
  - Chisels with straight edges.
  - Roundels and gouges (chisels with curved edges.)

- Rotary tools:
  - Rotary drills were turned with a bow, to grind a cylindrical hole.
  - The "running drill," not a drill at all, but more like a bow-driven die grinder, was used to cut narrow grooves.

- Tools that divide stone by pushing:
  - Wedges, which are inserted into pre-existing cracks or drilled holes, or a chiselled groove, to split large blocks using expansive pressure.
  - Pitching tools and hand sets, which look somewhat like chisels, but push directly on the stone, rather than penetrating and wedging.

- Hammers and mallets for driving punches, chisels, pitching tools, wedges, etc.

The status of one class of tools remains in doubt. Scholars disagree on the extent to which mechanical aids to copying and measurement were used in the ancient world. Some simple techniques are known to have been used in the Classical period, and it is almost certain that more advanced techniques were employed in subsequent Hellenistic period, but whether these advanced techniques were used by Classical sculptors is subject to debate. However, while their use in the Classical era is not certain, it would be remarkable if sculptors in the era between Pythagoras and Euclid were not aware of the geometric principles underlying the use of triple calipers. We have a very good picture of how quickly these techniques can be developed from the example of the Renaissance, when Italian sculptors developed a range of scaling and copying techniques within a few decades of the beginning of the resurgence of interest in Classical styles.

2.0.2 Stone

A few varieties of stone, like steatite (soapstone), and alabaster, can be whittled with an iron or bronze knife, or even with a stone or bone tools, and are thus always considered soft. At the other extreme, granite, basalt, diabase, and porphyry are difficult to scratch even with the best quality modern steel, and are thus always categorized as hard. All forms of limestone and marble, by

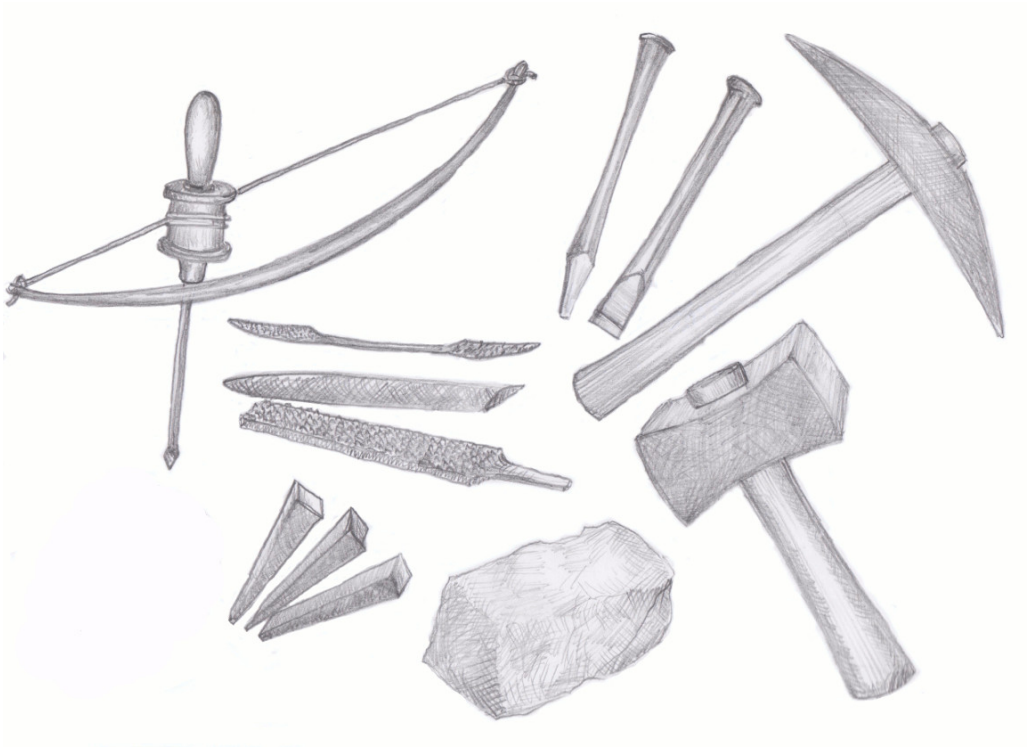

Figure 2.1: The traditional tools, clockwise: bow drill, punch, chisel, pick, hammer, pumice, wedges, and rasps in the center.

far the most important stones to sculptors, are between these two extremes, and are thus categorized as "medium hardness." Some varieties are harder than others, but all medium hardness stones can be worked with steel tools. However, marble is on the borderline for carving with bronze and wrought iron tools. These metals are not hard enough for some fundamental marble sculpting tools.

A few fundamental properties of stone determine most of the techniques of carving. First, stone has tremendous compressive strength, but little tensile strength, i.e., is hard to crush, but relatively easy to pull apart. For instance, the tensile strength of marble (although it varies slightly with the variety) is about $50.6Kg/cm^2$ ($720psi$), while the compressive strength is around 1120 kg/cm^2 ($19,000psi$). Equally importantly, unlike metals, stone has only the most minute ability to bend, stretch, or deform; if you if you hit it hard enough to exceed its compressive strength, it doesn't dent, but is crushed to powder. If you exceed it's tensile strength, it stretches only microscopically before it simply parts.

Stone working tools take advantage of these properties in different ways. One of the simplest techniques for working stone is to strike the surface with something even harder, such as a ball of hard stone, shaped to concentrate the impact, in order to pulverize a spot on the surface. Modern bush hammers do the same thing, but with an array of pyramids to crush several spots at a time. Abrasives also remove stone by pulverization, but do so from countless tiny points of pressure at once. Each of many hard corners of the abrasive grains apply intense pressure to a microscopic area, pulverizing a fine scratch across the surface, together wearing away the surface a fraction of a millimeter at a time.

Tools such as punches, which penetrate the stone to split away chips, pulverize a small amount of stone as they penetrate the rock, but the stone they remove in this way is incidental. The penetration is primarily a means to take advantage of the stone's low tensile strength. The stone beneath the tip of a punch is crushed by the concentrated pressure of the tip, but the sides of the spike spread the outward pressure over a much broader area, and acting as a wedge, burst loose much larger, more or less intact chips. The punch is most often used at a low angle to the stone, and the chips thrown outward, perpendicularly to the direction of the hammer. It can also be used straight–in, at a right angle, in which case the chips are ejected backwards, from all around the tip.

Note that the outward pressure of the punch does not have to exceed the tensile strength of the entire area of the chip—the rigidity of the stone concentrates the outward force at the leading edge of the crack. A propagating crack is like the tearing of cloth: a tear is difficult to start, but once it is started, any further pulling force is focussed on the few threads at the leading edge of the tear, allowing it to propagate with little more force than is required to break the next single thread. In stone, the discrete crystals act like threads in cloth, interfering with the propagation of tiny cracks. Each hard little crystal tends to interrupt the concentration of force at a crack's leading edge, acting

like the three-dimensional equivalent of one of the extra strong threads that are interspersed in rip-stop nylon.

Glass (e.g., obsidian) is the most extreme case. Glass has very high tensile strength (which is why fiberglass is used to reinforce plastic resins) but its uniform and non-crystalline nature allows outward force to be so intensely concentrated that a crack, once started, propagates almost effortlessly. This makes glass more or less uncarvable, except by grinding.

Almost all other stones have significant crystalline structure[3].

Edge tools, driven straight-in, also work by exceeding the tensile strength of the stone, but they are not used to pop away superficial chips. Heavy chisels used in this way crush their way into the stone for only a very short distance, after which the wedging pressure to the side becomes so great that a large chunk can be split from the stone. As with a punch, the leading edge crushes into the stone, starting fine cracks, but the broad sides behind the edge diffuse the outward force over too large area to crush. Thus, much of the force of the hammer is delivered outward, to the side, against intact stone, allowing a relatively small force to crack loose a large amount of waste.

Edge tools driven in at an angle, on the other hand, are mainly for finer carving. They are designed to shave away a thin layer, usually the uneven stone left behind by a penetrating tool, such as a claw chisel. This action is very different from the right angle stroke in that, ideally, it produces mostly powder and chips of negligible size. When carving marble, producing chips with the oblique chisel stroke tends to be a bad thing, because part of the mass will often be pulled from beneath the otherwise smoothed plane of the chisel's passage, leaving irregular pitting.

Wedges also split stone with outward pressure, but they don't bash their way into the stone by force. Instead, they are placed in a rows of pre-drilled holes, and the outward pressure slowly increased across the entire row. A handful of wedges, tapped with a two pound hammer, can split a stone the size of a car. Stones that have a very pronounced layering can sometimes be split effectively by driving hardened wedges directly between the leaves, but this used mainly by masons, not sculptors.

Pitching tools look superficially like chisels, but actually belong to a class of tools they do not deliver outward force to the side, the way chisels and wedges do. Instead of having an edge, these tools have a flat face that is designed to push directly on the stone, transferring the hammer energy to the stone without significant penetration. When driven against the stone at an angle, the corner of the face bites into the block a millimeter or so, allowing the flat face to deliver the hammer's momentum in line with the swing, to propagate the minute cracks that were started by the sharp corner. Pitching removes a lot of stone quickly, but it only works from the outer edges, and is thus most often used applying a rusticated surface of broken stone to the face of a squared block.

[3] Except for a few stones, e.g., quartz crystal and jewels stones, in which the entire stone is a single large crystal.

2.0.3 Metal

Gold, silver, and copper have been in use since before the historical record, but these metals are very soft. The discovery of bronze, an alloy of copper and tin that is much stronger than either metal alone, ended the Copper Age, and revolutionized society across the Mediterranean when the technology was developed sometime around 3300 BCE. Bronze was was the first metal of which reasonably hard tools could be made[4]. The weapons, armor, and tools that bronze made possible, as well as the resulting trade, not least, the trade in the metals themselves, propelled the greatest social revolution since the development of agriculture made cities possible.

Bronze is a relatively easy metal to work with because the component metals, copper and tin, can be smelted from ore at easily attainable temperatures, and the liquid metal can be cast directly into usable shapes, by pouring it into molds. Unfortunately, even the best bronze is a marginal material for stone-working. It can be made just hard enough to penetrate marble, but not hard enough to support the full range of techniques for working stone. Bronze tools can penetrate marble only when driven at a right angle to the surface, but they are not hard enough to bite into the stone, and tend to skid off of the surface when driven obliquely[5].

The discovery of techniques for manufacturing and working iron, which had once been more precious than gold, began in the Mediterranean world sometime between 1200, BCE and 1000, BCE[6], but the complex and difficult metallurgy of iron ensured that that bronze would remain superior to iron in almost every respect for many centuries more. Until steel making was mastered, iron's chief virtue was that it was cheaper and more abundant than bronze, which remained superior to iron in almost every way.

Steel is much harder to make than bronze or iron with the wrong amount of carbon, and harder to work with. The iron in iron ore is in the form of various oxides—rust, basically—mixed with various other minerals. Smelting iron from ore requires a temperature high enough to liquify the metal. This temperature is far higher than the melting point of tin or copper, and is difficult to achieve with primitive technology. However, with the right ores, wrought iron can be made at a temperature lower than is needed liquify the metal[7].

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[4] Although copper is ordinarily very soft, "cold forging" can make some non-bronze copper alloys as hard as some bronze. This technique, however, is more applicable to edged weapons than to stone working tools, which take much more abuse and have a short working life without constant maintenance. Unlike copper, bronze does not harden significantly under cold forging.

[5] Rudolph Wittkower cites experiments conducted by the Belgian sculptor H. J. Etienne, using bronze tools made of alloys similar to those available to the ancient Greeks [Wittkower 91].

[6] Meteoric iron, the rarest of the metals found in nature in metallic form, was known long before the Iron Age, but it was regarded as a precious metal. Meteoric iron can be easily distinguished from manufactured iron by its high nickel content.

[7] In making wrought iron, the oxygen is chemically removed from the oxide (i.e., the iron oxide is "reduced") without the metal ever being in a liquid state. The initial result of this processing of the ore is an impure spongy blob of iron particles and mineral slag, called a "bloom." The bloom must be worked (i.e., wrought) with heat and hammering, to shake out the crumbly mineral slag, and pressure-weld the iron particles into a solid bar. The resulting

Unalloyed iron is as soft as aluminum, but when a small amount carbon is added, it becomes steel, which is much tougher, and equally importantly, can be both hardened and softened with heat-treatments. Small amounts of other metals can also be added to the alloy to enhance various properties, but carbon is the key additive. Copper and tin, mixed together and heated, automatically yield bronze, but steel requires significant chemistry, at extraordinarily high temperatures, combined with a very specific sequence of physical and chemical manipulations of the evolving product. If making bronze is like making soup, then making steel is more like making mayonnaise. With too little carbon, the metal is softer than bronze; with too much carbon, the metal can be broken up with a hammer. Moreover, unlike bronze, which is easy to cast into usable shapes, malleable iron and steel are usually forged, i.e., heated red-hot, and beaten into the desired rough shape. The rough forged blank must then be softened with heat treatment, after which it can be milled, filed, and ground to the final shape. Finally, the finished object must subjected to a series of post-manufacture chemical and heat treatments to harden it for use.

The most technologically accessible techniques for making steel involve laboriously adding carbon to soft iron while it is in a solid state. The most important way of doing this was by allowing carbon from charcoal to soak into the surface of the hot iron, then repeatedly hammering the bar flat, folding it, and forge-welding it back together, until the sufficient carbon was dispersed throughout the metal[8] Steel good enough to work stone was probably too expensive to waste by making an entire tool out of it. Although no carving tools of the period have survived, it is likely that high-quality steel would have been conserved by forge-welding[9] hardened steel implants into soft iron tool bodies, a process which was still common well into the 19th Century, and continues to be used today in the best Japanese hand tools. Steel manufacturing took centuries to master, and was reinvented several times, having appeared in both East Africa and Turkey as much as a thousand years before it appeared in useful quantities in Greece, at the end of the Archaic Period, in the late Sixth Century BCE.

2.1 The Ancient Carvers

The precise date at which the full modern tool set appeared (implying the use of steel) is not known, but Sheila Adam's comprehensive study of Greek carving

metal tends to be of poor quality, soft, and full of impurities.

[8] A few ancient cultures could also produce iron in volume, much as is done in the modern world, by smelting ore using coal or coke. The resulting cast iron, however, then as now, has an extremely high carbon content, making it too brittle for many structural applications and tools. Until the middle of he Nineteenth century, industrial steel production mostly still relied upon carbuerizing wrought iron. The Bessemer process, patented in 1855, for converting pig iron into steel by removing the carbon, drastically reduced the cost of steel and increased the supply. This process was the most important technological discovery of the Second Industrial Revolution, which began in about 1850.

[9] Two pieces of clean iron or steel that are hot, but not molten, can be welded by beating them together between hammer and anvil.

in 1966 fixes a loose lower bound at sometime the late Sixth Century BCE[10]. Greek sculptors at the beginning of the Early Archaic Period (app. 660 BCE to 580, BCE) certainly lacked steel tools, and were limited to bronze and wrought iron. Carving at the beginning of this period was therefore accomplished without the use of modern chisels, and sculptors relied primarily upon the punch, driven directly into the stone at a right angle, for marble sculpture. These early sculptors gradually reduced the block, more or less evenly from all four sides, by punching thousands of shallow craters into it with the punch.

The punch marks are distinctive. Each crater is roughly conical, with the inner face broken, rather than crushed, with a puncture-mark at the bottom. As the stone neared it's final form, a progressively lighter touch was used, producing smaller and smaller craters in the stone[11]. At any given point in the process, the entire sculpture was completed to approximately the same degree on all sides. The final smoothing was accomplished by manually grinding the punched surface with stone or emery[12], a process which seems unimaginably laborious to a modern carver.

Fortunately for historians of art, several examples of unfinished Archaic Period carvings in various stages of completion have survived. It can be inferred from these examples, as well as from the appearance of finished pieces, that Archaic sculpture was generally executed from rectangular blocks, apparently without mechanical measuring devices. These blocks were often roughed out at the quarry to reduce the weight before shipping. Blüemel [Blüemel 48] cites a number of examples of roughed out pieces that for one reason or another never made it out of the quarry, and lay where they were abandoned until modern times. Drawings on each of the four vertical sides were projected through the block by punch-work, almost as if the roughed out sculpture had been cut out of a rectangular block using a band saw, first from front to back, and then from side to side. The result was that in the early stages, in any horizontal cross section, the front, back and sides of the sculpture were parallel respectively to the front, back, and sides of the original block.

Both the surface qualities and the form of Archaic Greek sculpture reflect the simplicity of this carving technique. The figures are simple and monolithic, with hands and arms attached to the body, and both feet on the ground. Detail tended to be superficial as seen in Figure 2.2. The four sided approach propagated all the way to completion. Archaic figures, particularly male figures, tend to be designed for four viewpoints, corresponding the original four sides of the block. The use of the straight-in punch is at least partly responsible for the simplicity and generally monolithic nature of Archaic sculpture for two reasons.

[10] See Shiela Adam's *The Technique of Greek Sculpture* [Adam 66].

[11] Some authors describe the progression as being to smaller and smaller *tools*. The rationale for this assertion is not clear—the size of a punch at its tip is the same regardless of the tool's overall size. Progressively lighter blows with the same punch seems more likely.

[12] Emery is a complex mineral composed largely of corundum, a crystalline form of aluminum oxide, Al_2O_3, which is the second hardest material found in nature, capable of scratching anything except diamonds. Rubies and sapphires are corundum colored with trace amounts of other elements. For thousands of years, emery was found in abundance only on Naxos, one of the Cyclades Islands, and is in fact named for the Emeri Peninsula on Naxos.

Figure 2.2: Kouroi from the Archaic Period, c. 600 BCE

The first is that the punch cannot be used straight-in on unsupported stone. The most natural way to work around this limitation is to keep all the masses connected to the core of the statue. The second is that the straight-in stroke is inherently coarse grained. Even with a light touch, the punch leaves a puncture of variable depth in the otherwise undisturbed stone at the bottom of the crater, below which there was insufficient sideways pressure to rupture the stone. The distance from the punched surface to the bottom of the deepest punctures is the closest the punch-work can get to the finished surface, and to get even that close takes a lot of punching, with the number of punch holes increasing rapidly as they get closer together[13].

Unworked marble is normally translucent. A direct impact produces a region of microscopic cracks under the point of contact, causing a permanent milky opaque cloud in the stone, extending to a depth of as much as 1/2 inch or more, depending on the kind of stone, the shape of the object hitting it, and the force of the impact. Bruising has been carefully avoided by most marble carvers since the Renaissance, but ancient carvers usually deeply bruised the stone all over by punching straight-in, and therefore, Greek marbles typically have a soft, matte, opaque appearance, more similar to limestone than to the luminous translucence of modern marble sculpture.

The effect of bruising is more than cosmetic. Bruising is a mechanical disturbance of the integrity of the stone that makes the surface softer and more absorbent, and therefore more susceptible to the effects of weathering. A record of the cratering process can actually re-emerge on pieces that were once smooth, when they have weathered, as the deeper bruised areas will erode more quickly. However, bruising had at least two desirable effects for ancient carvers: first, it probably made the laborious process of smoothing easier, and second, the more porous surface would have been more receptive to paint and other coloring treatments that were customarily[14] applied to almost all white marble in the ancient world. Figure 2.3 shows what Classical Greek carving looked like at the time of its creation, as imagined by the Victorian painter Lawrence Alma-Tadema. It depicts Phydias showing his new work on the frieze of the Parthenon to a group including Pericles, Socrates, and their respective lovers, Aspasia and Alcibiades.

It is known that the basic steel tools, which had first appeared in the Archaic Period, were fully developed prior by the beginning of the Classical Period, which nominally began in 480 BCE, with the Greek victory over Persia.

The evidence of tool marks and sculptural styles, suggests that the emergence of the full range of uses of the tools was a gradual process driven by the evolving metallurgy. Despite clear evidence that all the basic tools existed as early as the

[13] Cutting the distance between points in half quadruples the number of times it must be done. Cutting the distance by three quarters implies eight times more punchings, and so on.

[14] Greek sculptors made one major exception to the general practice of painting sculpture: the flesh of women was usually left pure white. This was also the custom in decorated pottery. Men's flesh was usually colored, and women's left white.

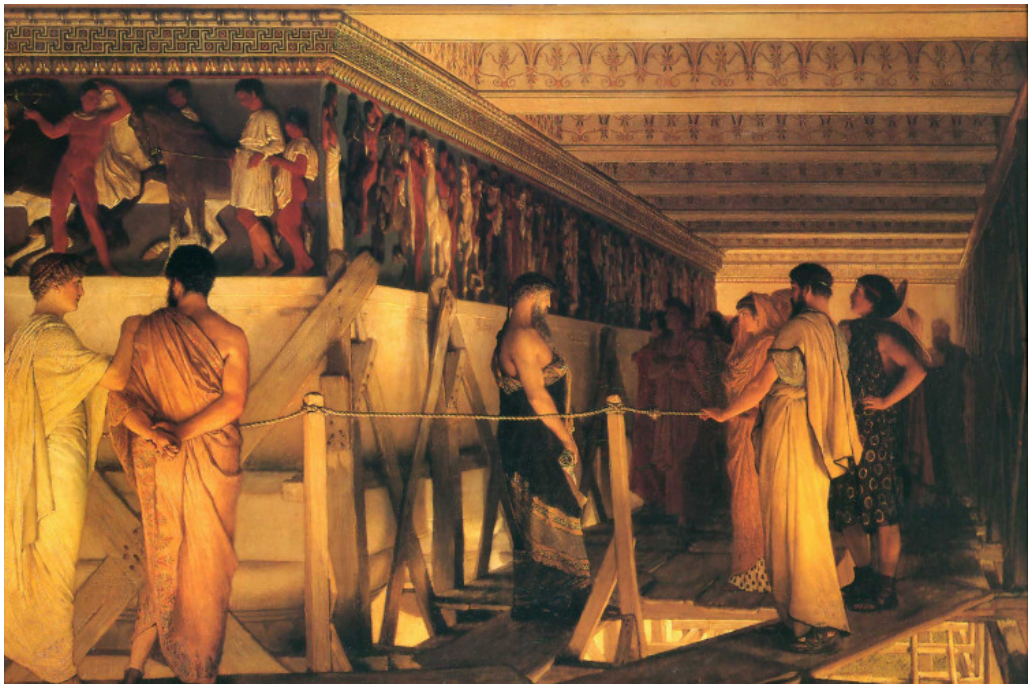

Figure 2.3: *Phidias Showing the Frieze of the Parthenon to his Friends*, Lawrence Alma-Tadema, Birmingham Museum and Art Gallery, Public domain, via Wikimedia Commons.

Sixth Century BCE, the punch, for instance, continued to be used in the old way throughout much or all of the Classical period[15]. Also as in the Archaic Period, it remained characteristic of the Classical Period that pieces were worked on from all around, and at any given point in the process, were finished to a more or less uniform degree on all sides.

Classical sculpture was apparently executed without direct mechanical copying, but plumb-lines and measurement from models are known to have been used, and can be seen in surviving illustrations of artists at work [Blüemel 48] pps. 48,49. The greater complexity, originality, and naturalism of sculpture made preliminary models essential, but the sculptor's primary reference at the level of the hammer stroke appears to have remained the the evolving work itself, rather than a reference point transferred from a model.

The work of the Classical Period, though more natural and expressive than the Archaic style, still reflects the limitations of the carving tools to some degree, in the softness of the curves and in the relatively simple compositions, as seen, in Figure 2.4, Dionysus reclining, originally from the pediment of the Parthenon, and carved at the apogee of the Classical Period. Even when figures appear on groups, in this era, as in pediment figures, they still retain some of the old monolithic spirit.

With the more capable tools introduced in the late Archaic period, the standard sequence ceased to be punch followed directly by grinding, as the practice had been in the early Archaic Period. From the late Archaic on, punch work was

[15] The absence of evidence of the use of the oblique punch stroke in this period is often attributed to tradition, but there is also a good technological argument for its protracted use.

- For the oblique stroke to be effective, the punch must penetrate relatively deeply in order to produce thick, intact chips strong enough to pull out a broad area of stone to the sides. A wide angle punch, when used in this way, breaks up the overlying stone too early, and thus tends to gouge only a narrow channel. However, when used straight-in, it is the wide angle that has the advantage, because in this mode of use, the stone does not burst to one side, relieving the outward pressure prematurely, allowing it to remove much more stone. Moreover, less penetration means it does not leave as deep a puncture in the center of the crater as a narrow punch would, and can thus get significantly closer to the finished surface.

- Because the wider tip is stronger, at the lower limit of steel quality necessary for the straight-in stroke, we can expect that the oblique stroke cannot be supported. However, claws and flat chisels, which do not penetrate deeply, and are not hit nearly as hard, are subjected to less stress than the oblique punch. Thus, as steel evolved from low-quality wrought iron, we should expect to see a progression from broad-angle punch only (poor quality steel), to broad-angle punch plus less-demanding tools such as claws (moderately good steel), and lastly, to use of the oblique punch. This is in fact consistent with what we see in the beginning of the Middle Iron Age.

- Another advantage of the straight-in punch is that it bruises the stone more deeply than the oblique stroke. This would be a disdvantage to the modern sculptor, but Classical sculptors usually bruised the entire surface. Among other advantages, bruised stone is softer, making it easier to work in subsequent stages, thereby extending the range of tool designs for which marginal steels are adequate.

In this period, we also see the claw chisel used in the vertical mode, in which it functions more like a bush chisel, more frequently than in subsequent eras, which further argues that the steel was marginal.

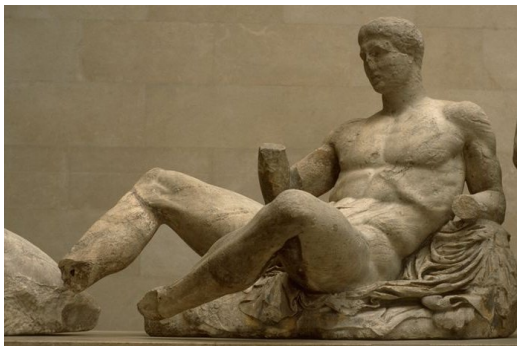

Figure 2.4: Dionysus, from the pediment of the Parthenon, Classical, c. 438 BCE

followed by further superficial carving with the claw chisel, sometimes progressing on to flat chisels and roundels, or bull-nosed chisels, prior to grinding. Both finished and unfinished Classical Period carvings showing the full progression of tool marks still exist.

2.1.1 The Drill

One of the things that is most striking to a modern stone carver is how much the drill was used by ancient carvers, and indeed, continued to be used until the early Twentieth Century. In the last century, pneumatic tools and rotary grinders have taken over much of the work that was once done with drills.

Ancient carvers made extensive use of several kinds of drills that worked by at least three different mechanisms: (1) grinding a hole into the stone by rotating the bit, like a modern drill (2) wearing a hole into the stone by tapping—the modern equivalent is a star drill (3) grinding a slot with a rotary bit applied to the side.

Drills in the ancient world could be as simple as rods tipped with flint or metal, that were twirled between the palms[16] or twisted like a screwdriver, or metal bars with a chisel-like end, that were tapped with a hammer as they were turned, to slowly wear a hole into the stone. Braces, i.e., drills turned directly by a crank that is inline with the bit, were known to the Greeks, but these turn at low speed, and are usually more effective at driving augurs for boring wood. More complex mechanisms, turned with a cord or strap, were standard equipment for stone carvers in the Classical age. Bow-powered rotary tools were common as late as the middle of the Twentieth Century, for both wood workers and stone carvers[17], and are known to have been used by workmen of

[16] Drills twirled between the palms are still used today, for instance in the course of mechanical copying, to adjust the precise depth of a hole being drilled to mark the location of the finished surface, which would typically be measured to approximately one millimeter accuracy.

[17] As late as 1939, Malvina Hoffman, in *Sculpture Inside and Out* [Hoffman 39] still clearly

the Classical period, because their use is depicted in a number of art works, although no images exist of them specifically being used on stone. The use of strap powered tools, similar to bow powered tools, but operated by one worker while being turned by another, can be probably be safely inferred, because the size of many of the holes exceeded the size what can be achieved by a bow. Smaller bow drills from recent times often have a handle at the top for applying pressure, while larger drills usually have a chest-pad that the user could lean on. Crank powered tools are still in common use among woodworkers: a brace turns the augur or drill once for each rotation. Smaller drills turn the bit multiple times for each rotation. Other variants turn a push into rotation of the drill.

Greek engineering of mechanical devices was unsurpassed for many centuries, so it is unlikely that they did not develop these obvious refinements, and very likely others as well.

Drill bits made of both stone and metal were used, and the Mycenaeans, in the Second Millennium BCE, as well as the Egyptians more than two thousand years earlier, even used tubular copper bits[18] that sawed out a circular plug, although this method seems not to have been used by the more modern Greeks. The most common bits used in the Classical period were steel, with flat or rounded chisel-like tips. (The shapes of the tips are evident from the marks that remain.)

The rotary drill was used extensively for a variety of purposes. In addition to its use for making round holes for nostrils, ears, etc., and for affixing attachments, it was heavily used for outlining the masses, and for removal of stone from tight spaces, such as between folds of drapery. In this mode of employment, the stone would be honeycombed with holes so that it could more easily be removed with chisels and rasps.

From the Classical Period on, the running drill was heavily used as an aid to carving deep grooves, particularly the long vertical folds of drapery, but also in hair and elsewhere. The running drill was not really a drill in the modern sense, but more similar in function to a die grinder, in that it was not used to drill round holes, but to cut a channel. No pictures of ancient running drills are known, but it appears to have been turned by a bow or pulley arrangement, similarly to a drill, with the bit being pushed or drawn along the surface as it turned, cutting a shallow groove that was deepened and widened by successive passes. Though now extinct, this tool, like the bow drill, was in use as recently as the early Twentieth Century.

The running drill is believed to be the only carving tool used in Classical Greece that did not yet exist at the end of the Archaic period. Blüemel [Blüemel 48] states that the running drill was in use in the middle of the Fifth

thinks of electic drills as exotic machinery, referring to an electric hand drill as "an electrical drilling machine," and apparently uses only manual tools in her own studio. She herself is shown using a simple drill twirled between the palms for the precision drilling used to mark copying points. This practice is still common even now for this one special purpose, because it is easy to control the depth of the hole.

[18] Tubular copper bits did not have metal cutting edges, but instead applied pressure to dry sand, which was poured into the kerf. See Ancient Egyptian Materials and Industries, [LucasHarris 62].

Century BCE, but a considerably later date of 370 BCE is given by Sheila Adam, in her highly regarded 1966 work [Adam 66] on Greek sculptural technique, and Stewart [Stewart 75] splits the difference, asserting that it first became common at around 370, but that it was known 70 years earlier. The date given by Adam appears to be at least 70 years too late, and indeed, even Blümel's estimate may not be early enough, but all three estimates post date the nominal beginning of the Classical Period in 480 BCE. Like many more modern carvers, Classical Period carvers often overused the drill, and at times, it can become intrusive.

The use of the drill is obvious and unmistakable when it is used to make round holes, but distinguishing slots made with the running drill from slots cut with the aid of the drill can be tricky. However, there are a number of indicators. The first is that the running drill cornered poorly; if a groove has bends, it was probably drilled. Also, the direct marks of both tools took a lot of work to remove completely, so traces of the tools are often visible on the bottom and sides, particularly in deep cuts and in areas that would not be easily seen when the work was installed. Circular traces of the drill often remain on the bottom of slots, as do semi-cylindrical vertical scoops on the sides. The running drill does not leave either kind of trace, because it does not cut from the face. Instead, it was worked back and forth as it rotated, cutting a straight, or gently arcing groove of unwavering breadth, leaving distinctive long, shallow, waves on the bottom, which often terminate with a crease where the linear motion stopped and reversed repeatedly. Unlike the drill, the running drill needed little cleanup on the sides because it cut a slot, rather than a row of cylinders. Therefore, the chisel and rasp marks on the sides of drilled grooves are usually an indication of the use of the drill, even if the cylinders have been entirely obliterated. All of these marks can be very apparent when illuminated from a low angle. Note that the use of one of these tools does not preclude the use of the other. Modern sculptors sometimes use the drill first, and then clean out the webbing with a grinder, which is the modern equivalent of the running drill. There is no reason to suppose that ancient carvers did not do this as well.

On many carvings of the Classical and Hellenistic period, entire areas seem to have been carved primarily with the drill and/or running drill, particularly drapery, where the use can be spotted wherever long parallel folds of drapery are seen. Note the examples shown in Figure 2.1.1 detail of a grave stele from Piraeus, Attica, C. early–Fourth Century BCE. On the left we see running drill work that looks almost as if it were done with a router. Note the long slots of unvarying width between folds. A narrow bit has been used to cut the slots between the fingers. Note the long narrow channels of unchanging width. On the right we see relatively crude work with a drill to separate the folds in the the garment. The remains of cylindrical holes are visible particularly at the lower ends, but at the bottom, particularly on the far right. Rough chisel work also remains, which together with the incomplete removal of the webbing between the holes, simulates the bunching and wrinkles of the fabric.

Both of these tools remained common until power tools made them obsolete, and bow-drills are still used by traditional carpenters in remote areas, so it is possible that somewhere, the bow-drill is still used on stone, but both tools are

Figure 2.5: Use of running drill (L) and drill (R) early–Fourth Century Greek grave stele.

more or less extinct in the developed world.

2.1.2 The Pressures of Commerce

The cultural context in which sculpture was made changed radically after Greece became an empire. Prior to and throughout the Classical period, sculpture had been primarily for public and religious purposes, but the international trade that flourished in consequence of the Athenian Empire and the subsequent Macedonian Empire founded by Philip II and advanced by Alexander, produced a far more cosmpolitan society, and a class of wealthy people who used architecture and sculpture as a way to display their personal wealth and status, and of course, as objects of beauty in their own right. Simultaneously, Rome was increasingly occupying a similar role in the Western Mediterranean, and developing its own class of wealthy conspicuous consumers.

The Hellenistic Period, which begins with the death of Alexander the Great in 323 BCE, at the peak of his conquests, saw the diffusion of Greek culture across the Mediterranean world and the development of a large and growing market for sculpture throughout the region, a market that would only grow in the centuries that followed.

The Laocoön Group,in Figure 2.6 is an example of the radically freer and more naturalistic styles that developed in this environment. The fluidity of both the overall composition and the surface modeling of Hellenistic sculpture are remarkable when compared to Archaic and even Classical Period work. Work of such complexity is virtually impossible without some degree of mechanical copying, which was increasingly used, both for producing originals from models, and for copying existing masterpieces. Copies of the great Greek works were made in large numbers, and many of the works of the Classical Period, particularly bronze sculpture, are now known only from marble copies done during this period, and subsequently by the Romans, who absorbed the Greek traditions wholesale, adding their own aesthetic spin.

Figure 2.6: The Laocoön group, Hellenistic, c. 42 BCE

Hellenistic artists abandoned the traditional practice of sculpting from all sides equally, and characteristically worked front-to-back, with the front often approaching completion even as the back remained embedded in the block. All of the basic tools, used in essentially the modern way, are in evidence.

Sculpture continued to be used in public buildings and temples, but a vast new market opened up as well, among the wealthy citizens of the Greek and Roman Mediterranean. These new patrons loved not only figures and compositions from mythology, but for the first time, genre sculpture became popular: images of ordinary people, often not even beautiful people, and of the gods, and minor deities in informal situations.

Even in the Classical Period, the pressures of celebrity were already introducing a degree of distinction between the creative act and the hands-on work of execution. For the first time, sculptors were famous personages. A corollary to the new practice of attaching the sculptor's name to works of art was (and remains) the impossibility of a famous artist who works on a large scale personally executing all of the work demanded of him or her by the public. The pressure to produce was as great for Phydias in the Fifth Century BCE as for Jeff Koons in the 21st Century CE, and this pressure only grew with the cosmpolitan markets of the Hellenistic period.

The evolving market for art in the Hellenistic period further widened the conceptual gap between the creative act and the execution, because well known pieces, both new and old, were routinely copied for shipment for customers who could be anywhere in the Mediterranean world. The commercial production of art made indirect carving indispensable, and indirect carving inherently discounts the resistant nature of the stone, because other people will be doing the

Figure 2.7: A reconstruction of the chryselephantine statue of Athena Parthenos from the Nashville, TN Parthenon replica, (Photo by Dean Dixon, sculpture Alan LeQuire.)

hard work. Even bronze sculpture, which almost always originates as clay or wax, was routinely copied into stone, a practice which frankly ignores the nature of stone and directly copies the flexibility of clay.

The separation of the creative act from the labor of the carving makes radically more complex compositions feasible, and inevitably frees the artist to be more ambitious, but at the cost of divorcing the the conception of the work from the properties of the medium. It is for this reason, that the issue has excited intense passion among artists and critics, with partisans of direct carving instinctively regarding indirect carving as a form of aesthetic cheating. The issue transcends logic, and it tends to be a relatively modern concern. There is a romance to stone, about artists doing their own work, and about Greece itself, that strongly colors even scholarly discussions of the subject. Yet the Greeks themselves were not romantic about stone the way we are. It was bronze, not marble, was the more[19] celebrated sculptural medium in Classical Greece, and the painters of sculpture were as famous as the sculptors—the carving was only one part of a finished piece. We know Greek stone carving better than Greek bronze, primarily because the high intrinsic value of bronze insured that the bronzes would be melted down the first time the metal was needed more for weapons than for decoration[20]. While it is impossible to fully understand the aesthetics of artists from an ancient culture, it would be surprising if master

[19] Neither was the *most* celebrated art form. Work in chryselephantine, i.e., composite constructions covered in ivory and gold, sometimes colossal in scale, had the highest status in Archaic and Classical Greece. The reconstruction pictured in Figure 2.7, of the statue of Athena Parthenos from the Parthenon replica in Nashville, TN, gives some idea of what these pieces were like. This reconstruction is a composite of images of the sculpture from ancient times, and is regarded by art historian as very realistic. No major works, and very few examples of any scale, have survived to the present day.

[20] This was even more true for gold-encrusted chryselephantine temple statues, at least some of which were made with detachable gold parts, which could be removed and melted down in time of need, and replaced with fresh castings after the crisis had passed.

modelers, accustomed to the quintessentially indirect process of bronze casting, who routinely painted marble, and decorated it with jewelery, weapons, and hair cast in bronze, when placed in charge of teams of stone carvers, would share the modern disdain for indirect carving.

After the Hellenistic Period, with one possible exception, the stone sculptor's tool kit evolved only incrementally until the early 20th Century, when electric and pneumatic power tools, ultra-hard metals, new abrasives, saws that could cut stone as easily as wood, and numerous other technologies, began to be introduced. The possible exception to this multi-milliennium technological stability is the group of advanced tools and techniques developed during the Renaissance for transferring three dimensional designs from a preliminary plaster model to stone. Evidence for the use of true pointing frames(see Chapter Indirect Carving 12) and the triple calipers in Ancient Greece is ambiguous, although they are known to have used fixed reference points on the works in progress.

Chapter 3

The Materials

This chapter covers the general properties of stone, such as hardness, toughness, and resistance to weathering, and discusses the particular properties of the stones commonly available for carving.

3.1 Hardness and Toughness

What we informally call "hardness," scientists and engineers recognize as a group of distinct but related properties that may or may not occur together in similar proportion. For instance, a material can be very hard, in the sense of being able to scratch other materials, yet have little ability to withstand an impact.

Think of two "hard" materials: oak and a soft sandstone. You might be able to gouge into the sandstone with a steel tool using only hand pressure, but be completely unable to penetrate the oak by the same means. On the other hand, a saw that could easily cut through the oak, would be quickly destroyed by the sandstone. Moreover, the chunk of sandstone could be used to grind away oak or steel, yet the same stone could be pulverized by hitting it with the oak block.

The sandstone is more abrasive than the oak, and the oak is tougher than the sandstone. So which is harder? It depends on what scale you use. The *Mohs* scale is the most common ranking of the relative hardness of minerals, ordering them in terms of which can scratch the other. If stone X can scratch stone Y, then X has a higher Mohs number. Scratching is the most useful criterion for stone, but there are many other tests for other materials. For instance, metal hardness is often measured by the *R*ockwell test, which measures how deeply a sample is dented by a standard impact.

While no single number captures all of a stone's properties, Mohs hardness captures a lot of what we care about in stone, so it is a good point of departure for describing the physical properties of a stone.

Talc, the softest solid mineral, is assigned the index 1 on the Mohs scale; you can scratch it with your fingernail. Diamond, which is scratched by no natural

mineral except other diamonds, is assigned a hardness index of 10. Minerals are given fractional numbers if they will scratch one of the Mohs minerals but are themselves scratched by the next. The scale is purely ordinal, meaning that the difference in the Mohs numbers for two materials is not necessarily proportional to the difference in their hardness, but only reflects their ordering. All that the numbers tell you is that the material with the greater number is harder, but you can't infer how much harder. For example, corundum (9), is considered to be twice as hard as topaz (8), but diamond (10) is considered to be four times as hard as corundum. Not every sample of a given minerals will have the exact same hardness. Even diamonds come in a range of hardnesses—the hardest varieties are prized for their ability to cut and polish the rest, something no other mineral can do.

The table below gives the reference mineral, familiar materials that can scratch them, and sculpted stones of comparable hardness. Anything material in the *"scratched–by"* column will scratch all materials with a lower Mohs number.

Mohs	Substance		Scratched By	Carving Stone
1	Talc		Fingernail	None
2	Gypsum		24-karat gold	Alabaster, soapstone
3	Calcite		Copper	Limestone, soft marble
4	Fluorite		Steel knife	Typical marble
5	Apatite(tooth enamel)		Granite	Hard marbles
6	Orthoclase Feldspar		Silica glass	Softer granites
7	Quartz		Tungsten carbide	Granite, diabase
8	Topaz		Sapphire, ruby	None
9	Corundum (ruby)		Silicon carbide	None
10	Diamond		Diamond	None

In English, the chart above tells you that stones softer than 5.0 or less can be worked with steel tools, that all carvable stones can be worked with carbide tools or silicon carbide abrasives, and that silicon carbide will cut anything except diamonds. The chart does not say it, but in practice, stones with a softness around of close to 2.0 can usually be worked with knives and hand saws made for woodworking. Stones harder than 2.5 will quickly damage knife–like tool edges, so wider angle bevels and with a harder temper are necessary.

Most sources still report what this chart suggests, that industrial silicon carbide is second only to diamond as the hardest substance, and this was true until relatively recently. However, cubic boron nitride, also called cBN, another synthetic material, is significantly harder than silicon carbide, and is available in the form of grinding wheels and burrs. Tools made of cBN are primarily for high–tech machining, and are not hardware–store items, so for most artist's purposes, silicon carbide and diamond are the two hardest abrasives.

Aluminum oxide-based abrasives will barely scratch granite and diabase, but cut marble easily. While excellent for grinding and sharpening steel tools, they will not work on tungsten carbide. Silicon carbide, often sold under the commercial name Carborundum, is the abrasive found in green grinding wheels, and in many whet stones, and is used for shaping the hard stones, as well as for sharpening carbide tools. Silicon carbide grinding wheels can be dressed and re–shaped with diamond.

Both aluminum oxide and silicon carbide are usually bonded into a material that looks like stone, and are called "stones". The various abrasive stones are color coded, in addition to having their constituent abrasives and several other propertes encoded on the labels. For most purposes, it is enough to know that white, pink, blue, and gray are usually aluminum oxide, and can be used on most metals as well as on the softer soft stones. Green stones and dark gray stones are usually silicon carbide, which can be used on all stone, and steel, as well as on tungsten carbide tools. Diamonds tools usually look like plain metal with a slightly rough surface. They will grind anything, but the are not usually either necessary or well suited for grinding sculptural stone. The are excellent, however, for circular saw blades, which will easily cut granite.

Though diamond is by far the hardest natural material, it is not very tough—you can pound one into powder with a soft brass hammer. In fact, before the historically recent invention of techniques for sawing and grinding diamonds using diamond dust, diamonds were traditionally cut by cleaving, i.e., splitting on natural planes, using steel chisels. Thus, for processes that use impact on hard materials, rather than scraping, the best choice is tungsten carbide.

The difference between hardness and toughness is illustrated well by jadeite, which has a Mohs hardness number similar to that of granite, but is so tough that it was used for hammerheads by ancient stone workers, and can even be used to hammer steel tools.

Lines-of-cleavage and other anisotropies (physical properties that vary with orientation) are common features of many kinds of stone, especially of sedimentary stones such as limestones, and metamorphic stones derived from sedimentary origins, such as the marbles. For instance, such stones will often split relatively easily along the lines of their "bedding", i.e., the planes in which the original sediments were laid down. Even within a seemingly uniform block of marble, a carver will sometimes find that the same tool works differently from one side of the block than the other.

3.2 Weathering

Exposure to the elements attacks stone in many ways, and every kind of stone is vulnerable to weather some degree, but sensitivity varies. On a human time scale, granite and similar stones are more or less imperishable, whereas other stones might show the effects of weathering in a single year, and be substantially destroyed in less than a century. A partial list of the ways in which stone is attacked by the elements includes:

- Water that seeps into porous or cracked stone expands as it freezes, splitting the stone or crushing the fine structure so that it crumbles. Stone may appear to be untouched for many years, the abruptly fall apart in a year or so, as the damage reaches the point where the openings enlarge to some critical size.

- Ordinary rain will simply wash away some stones, particularly limestone. Acid rain rots and erodes all carbonate stones much more quickly.

- Other kinds of precipitation, e.g., snow and dew, can have the same effect as rain.

- Biological effects: Bird droppings attack many kinds of stone chemically. Lichen, moss, and other plants can inhabit cracks and pores in the stone, causing various kinds of damage, both chemical and mechanical.

- Extreme changes in temperature stress stone mechanically, with the hot sun expanding the surface relative to the cold interior.

- Naturally-formed minerals or salts deposited by water can attack the surface chemically, or damage it mechanically due to the growth of crystals.

3.2.1 Rain

Some marbles and limestones weather better than others, but all such carbonate stones will eventually be eroded by exposure to rain water. Even rain of natural acidity attacks the surface of marble, slowly rendering it chalky and porous, or giving it a sugary, crumbly texture. In time, the surface rot penetrates the stone and ultimately destroys the deeper structure of the stone as well as the surface.

Limestone erodes more gracefully, tending to wash away slowly from the surface in. Figure 3.1 shows the degree to which painted numbers have protected the surface of a limestone wall from erosion. The wall (in Park Slope, Brooklyn) was built around 1895, and the numbers were probably painted on much more recently, yet the painted surface is as much as 3/8 of an inch higher than the adjacent unpainted surface. The thickness of the paint itself is negligible; stone washed away by rain water constitutes almost all of the difference. Note that the lines of bedding (which happen to be horizontal) have been brought up as the stone washes away faster in some areas than in others. The right side of the same picture shows severe erosion on a carved piece of limestone. Note the emergence of tiny fossil shell fragments, and the exposure of the original sedimentary layers.

The effect of weathering is obvious on the majority of marble monuments and gravestones in North America that date from the second half of the 19th Century or earlier. Many are already in quite bad shape.

Figure 3.1: Left: limestone protected from erosion by painted lettering. Right: badly eroded limestone carving. Note shell fragmens and sediment layers.

3.2.2 Acidity

Acid rain accelerates this process. Water containing dissolved carbon dioxide is always acidic due to the temporary conversion of the carbon dioxide to carbonic acid. Almost all naturally occurring water has at least some carbon dioxide dissolved in it, because the atmosphere contains approximately 0.038 carbon dioxide.

Naturally occurring water is only slightly acidic because 0.038 is not a very high concentration. Soda water, on the other hand, is super-saturated with carbon dioxide. To see the sensitivity of marble to the acidity of rainwater in fast-motion, splash some fresh soda-water or cola stand on a clean piece of polished marble. Absent a protective coating such as wax or oil, even a brief exposure to fresh soda water will etch a matte-finished mark on the polished surface.

Rain more that is significantly more acidic than results from naturally dissolved carbon dioxide is known as "acid rain." The excess acidity results not from carbonic acid, but from sulphuric and nitric acids, usually derived from sulfur and nitrogen compounds that are injected into the atmosphere by burning fossil fuels. Volcanic eruptions can also produce acid rain. The deposition of the resulting acid may occur hundreds of miles from the point of origin, and need not be in the form of rain. Other kinds of precipitation such as snow, fog and dew, as well as direct deposition of acids in the absence of any visible precipitation, are also factors.

Acidity and alkalinity are specified by the pH scale. Pure distilled water is neutral, and has (by definition) a value of pH 7.0. Numbers between 0.0 and 7.0 indicate acidity, and numbers between 7.0 and 14.0 indicate alkalinity. Thus, ordinary water containing the normal concentration of atmospheric carbon dioxide is already slightly acidic with pH of 5.5. Rain with a pH less than 5.0 is considered to be acid rain. Very few aquatic animals can withstand a pH

of less than 4.5 to 4.0 and many die if the acidity as low as 5.0. In extreme cases, acid rain can be more acid than vinegar, which is approximately 2.9.

The following table gives a few sample pH values for comparison.

Liquid	pH Value
Battery acid	0.5
Lemon juice	2.4
Soda water	2.5
Vinegar	2.9
Acid rain	< 5.0
Natural water	5.5
Distilled water	7.0
Soap	9.0-10.0
Pure lye (e.g., drain-cleaner)	13.5

3.3 Carvable Stones

Only the most common carvable stones are described here—there are many more. Within these generic categories stones may have a wide variety of properties. Color can vary widely—marble, for instance, can be anywhere from snow white to black, or brightly colored.

You may find other stones quarried locally, or have access to fieldstone or stone from exposed outcrops. It may be worth identifying such found stones and try out their carving properties. Some are good for carving and others are not, either because of poor workability, deep effects of weathering, or because they contain asbestos or other hazardous minerals such as toxic metals. (Serpentine is a good example. It's great to carve, but many varieties contain asbestos.) It's a good idea to have any stone not specifically sold for carving looked at by geologist or rock-hound before carving it.

Artificial materials like brick and concrete can aso be carved with the same techniques.

3.3.1 The Carbonate Stones

The carbonate stones, of which limestone and marble are the most familiar, are composed primarily of calcium carbonate ($CaCO_3$), which mostly originates as the shells or skeletons of sea-life. A thick ooze of this material covered much of the floors of ancient oceans just as it does today, accumulating to tremendous thickness and eventually slowly hardening into chalk or limestone under the weight of overlying deposits.

The limestones are thus sedimentary rocks, being composed of either the original shells themselves, or of calcium carbonate that has dissolved from such deposits and subsequently recipitated from solution. Other minerals, such as sand and clay, may be present in smaller amounts, either uniformly mixed or con-

centrated in layers. You'll find sand, pebbles and even sea-shells and other fossils in many varieties of limestone. Calcium magnesium carbonate ($CaMg(CO_3)_2$) is present in dolomite and related stones.

The marble family, which overlaps to some degree with the limestones, are metamorphic. Marble originates as limestone, but is subsequently transformed by heat and pressure, which give the calcium carbonate a denser crystal structure. Although the original limestone may have once contained fossils, because of the metamorphosis, marble generally does not, although it may occasionally contain inclusions of other minerals. While some so-called marbles, notably Belgian black marble, may be alternately classified as limestone, and marble, conversely, sometimes be defined simply as limestone capable of taking a high polish, to a geologist, the key distinction is sedimentary vs. metamorphic. (Belgian black marble is thus technically a limestone, not a marble.)

Chalk is chemically identical to limestone, and of the same origin, but is softer and less compressed. Marl is chalk or limestone with an admixture of clay and mud originating from the outflow of ancient rivers.

Some carbonate stones originated not directly from sea-shells, but from calcium carbonate laid down in other ways.

Tufa, for instance, is composed of calcium carbonate that was precipitated from fresh water lakes which for one reason or another have been fed by mineral-rich waters. Similar to limestones originating in ancient seas, tufa is usually softer than ordinary limestone, and often has the property of hardening upon exposure to air. Some tufas, when fresh, are soft enough to cut with a carpenter's saw, yet become quite hard after a few years exposure to air.

Travertine is another limestone-like carbonate-based rock that is often called either a marble or a limestone, but is acutally formed by a very different kind of sedimentary process. Unlike the true limestones and tufa, which are formed by (¡i¿CaCO¡sub¿3¡/sub¿¡/i¿) deposits built up on the sea floor or on lake bottoms,respectively, travertine is (¡i¿CaCO¡sub¿3¡/sub¿¡/i¿) that has been deposited directly on land, or sometimes in caves. Travertine may form from the mineral-rich water that flows to the surface from hot springs, or from surface water that has drained through limestone strata in regions known as karst formations. Deposition of the dissolved (¡i¿CaCO¡sub¿3¡/sub¿¡/i¿) may be the result of several different processes, including evaporation or changes in temperature and/or acidity of the water.

The uneven surface of a growing travetine mass will often host deposits of moss and other matter that are eventually encapsulated, leaving the the stone riddled with holes and cavities. Stalactites and stalagmites are travertine deposited underground.

Marble

Marble has traditionally been regarded as the most perfect carving stone, for its beauty, its workability, and its capacity to take detail. It is quarried around the world, but many of the finest sculptural marbles are found in Italy. In the United States, marble is quarried in Vermont, Tennessee, Alabama, Colorado

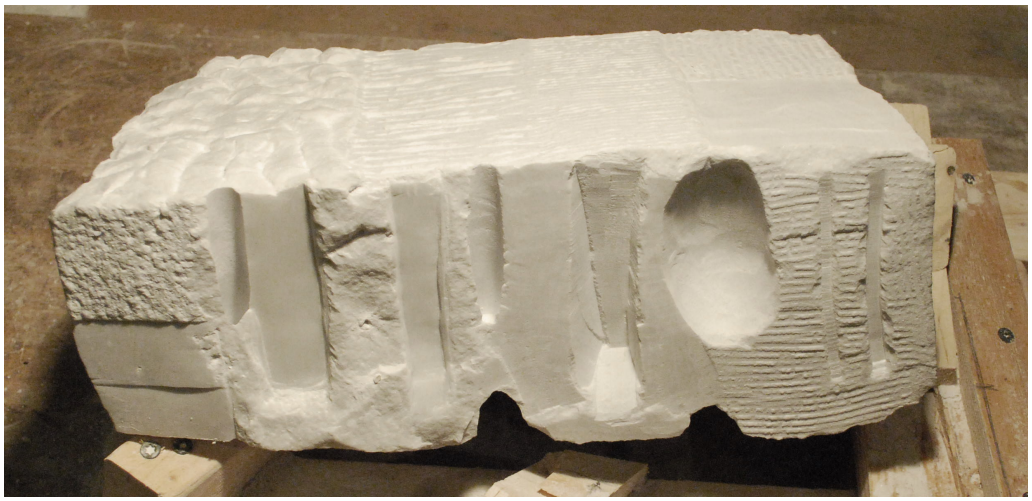

Figure 3.2: Block of Italian marble showing the marks of various tools.

and elsewhere. The Italian marbles are unmatched for figurative carving, not only for their mechanical properties but because the translucence of is similar to that of flesh, giving a life-like appearance.

Stones in the marble family are in the middle range of hardness, but all are soft enough to work with steel hand tools. Mohs hardness numbers range from 3.5 to 5.0. All of the manual and power techniques work well with marble: chiseling, splitting off chunks and flakes with a point, bushing, rasping, scraping and drilling. Marbles tend to be somewhat translucent, polish well, and take fine details. Marble comes in many colors, and may be perfectly uniform in appearance, heavily veined, or anywhere in between. Marble sold for carving varies widely in appearance and carving properties, with some of the varieties being very hard and brittle. Commonly available marbles may be pure white, shot through with smoky dark veins, or even nearly black. Other varieties are brightly colored or heavily veined with colors.

The so-called Dolomitic marbles contain, in addition to calcium carbonate, large amounts of calcium magnesium carbonate. They are very similar in appearance and physical properties to the true marbles. All varieties are subject to inclusions of other mineral and flaws which may or may not be detectable from outside.

Limestone

The limestones on the whole tend to be softer and coarser than marbles, although some limestones are harder than some marbles. Limestone is usually blander in appearance, often buff or gray in color. The stone is typically are in the Mohs 3.0 to 4.0 range of hardness. In general, limestone is usually relatively opaque, giving finished sculpture a deader look than marble, which tends

Figure 3.3: *Metropolitan Museum of Art*, c. 1910, Detail of facade showing use of Indiana Limestone

to be slightly translucent. Because it is often so bland, sculpted limestone is more often seen on buildings than as free-standing artwork. Fossil sea-shells are sometimes found embedded in limestone. As with marble, there are "dolomitic" limestones composed of calcium magnesium carbonate but also as with marble, these are not easily distinguished from calcium carbonate limestones either by appearance or by physical properties.

Many varieties of limestone withstand weathering and acid rain better than marble, and some varieties harden slowly after quarrying, due to evaporation of entrained water. Such hardening proceeds slowly from the outside in.

Limestone tends to be easily worked with hand or power tools. While some limestone can take a polish, these stones tend not to keep a shine when exposed to weather.

Sculpture is a very minor use of limestone. It is heavily used in industry as a construction material and a the raw material for making cement, quick lime, and lime for plaster. It is also used as fertilizer and as a buffering agent for neutralizing acids. In the United States, Indiana Limestone is the most commonly available type. It's color ranges from creamy tan to pale blue-gray, and the grain can be very even or varigated. It the most widely used architectural stone in the US, and is often carved for building ornamentation. Famous buildings constructed of Indiana Limestone include the Pentagon, the National Cathedral in Washington DC, and The Metropolitan Museum of art, The Empire State Building, and Grand Central Station in New York.

Figure 3.4: *Mount Rushmore Presidential Memorial*, granite, completed 1939, Gutzon and Lincoln Borglum

3.3.2 Granite, Basalt, and Related Stones

All of the stones in this family are igneous, being formed when large masses of molten rock (magma) orginating deep in the earth are forced to higher levels in the Earth's crust, where they cool and solidify into rock. The cooling depth can be anywhere from tens of thousands of feet down, to the earth's surface, and need not happen entirely at a single level. These rocks vary widely in chemical makeup, but but most are dense, hard, tough, extremely durable, and can be polished to a glassy finish. Stones that solidify deep in the earth are said to be "plutonic."

The appearance of these stones tends to be greatly affected by the depth at which they solidified from the molten state. Those that solidify deep in the earth cool slowly, giving them time to form large crystals of their component minerals. These stones (e.g., granite) tend to have a coarse visible structure, often differently colored grains fused into a single mass. The stones that solidify close to, or on, the Earth's surface (e.g. basalt) cool too quickly for large crystals of distinct minerals to form, and are thus finer grained and uniform in texture. Figure 3.4 is perhaps the most famous granite sculpture in the United States.

The great hardness of all of these stones, Mohs 6.5 to over 7.0, limits the

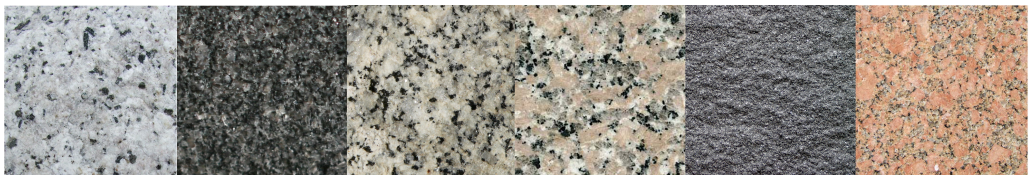

Figure 3.5: Six of the thousands of types of granite.

techniques available for working it sculpturally. Most of the constituent minerals are harder than hardened steels, especially quartz, which is harder than any steel alloy. Steel tools strike sparks of burning metal when hit against these stones.

Despite their great hardness, these stones do tend to split well, with either heavy carbide chisels or pitching tools. However, even carbide chisels tend to crush these stones superficially, rather than penetrate. While chisels can be used to break off chunks, it is difficult to chisel away controlled amounts, as can be done with softer stones, so hand techniques that rely on pulverizing away the surface of the stone are often used. Punches, flat chisels, and bush hammers are used to crush the surface of the work-piece, gradually reducing the stone to powder.

One way to remove a lot of stone quickly, in a controlled way, is to use a diamond saw to slice the region of stone that is to be removed into thin "leaves" that can be subsequently broken off with chisel and hammer. Machine-powered diamond or tungsten carbide burrs, and silicon carbide (Carborundum) grinding tools, are used for surface shaping and smoothing.

The silica content of these stones varies, but they all produce a glassy dust that is damaging to the lungs upon chronic exposure. It was said in the old days, that there are plenty of old marble cutters, but very few old granite cutters. Therefore, stones in this category should not be worked at home or in schools, where adequate protection and cleanup are generally not practical.

Granite

The granites family are felsic (i.e., rich in feldspar[1], quartz[2], and mica[3]). These stones solidified deep in the earth, cooling very slowly, and typically have a very visible speckling from the large crystals of the various component minerals. It tends to be best for simple sculptural shapes, both because of the difficulty of carving fine details, and because detail is obscured by the speckles.

[1] The feldspars are a family of minerals composed of silicon, combined with various combinations of the four metals calcium, sodium, potassium, and aluminum.

[2] Quartz is a crystalline mineral, $SiO4$, with the molecules arranged in the form of tetrahedrons of one silicon and four oxygen atoms. As each oxygen atom is shared among two silicon atoms, the overall formula is $SiO21$.

[3] Mica is a family of phyllosilicate minerals that have a crystal form of parallel sheets.

Basalt, Diabase, and Porphyry

Basalt, diabase porphyry are mafic, i.e., rich in magnesium and iron, and tend to have have similar working properties to granite, being dense, hard, and tough.

The magma deposits that form basalt cool either at shallow depth in the Earth, or are actually poured onto the surface, or onto the sea floor, by volcanos. In either case, they cool too quickly for large crystals to form, and thus have a fine-grained, blander appearance, somewhat like a dark limestone.

If the same magma that would form basalt if released close to the surface is injected more deeply in the earth's crust, the cooling is slower, and diabase, is the result. The slower cooling yields larger crystal sizes than are found in basalt, and a greater separation of the crystalized constituents. Basalt carving is most familiar from ancient Egyptian artifacts, but some contemporary carvers are using this stone too. A beautiful carving of a falcon by Tony Angel is shown in Figure 3.6.

Porphyry is a diabase-like stone that is characterized by two-stage cooling. First, a long, slow cooling, at great depth, allows large crystals to form in a still-molten matrix. The preliminary phase is followed by a rapid cooling when a subsequent upward movement of the magma toward, or even onto, the Earth's surface. The rapid cooling freezes the molten matrix into tiny crystals, leaving the large crystals embedded in a homogeneous background. The mix of the two scales of crystallization gives porphyry a beautiful and decorative appearance.

Despite the hardness and toughness of these stones, incredibly, the ancient Egyptians were able to carved these stones by pulverizing away the surface by pounding it with balls of still-harder diorite. Diorite is a related, relatively rare, igneous rock that was slowly cooked above a subduction zone, where the cool crust is being slowly re-ingested into the Earth's molten mantle. More remarkably, the Egyptians also drilled and sawed these stones by using relatively soft copper and bronze tools to impart motion and pressure to abrasive sand, much as modern stone workers do with abrasive fiber wheels.

Obsidian

A more exotic igneous sculptural stone in this class is obsidian, which is a dark gray, green or black black volcanic glass, similar to quartz. Obsidian is composed primarily of silicon dioxide originating in magma, but cooled so quickly that it is *amorphous*, meaning that it has has no crystal structure at all, like glass or jello. Obsidian is harder than marble, but much softer than granite or basalt, having a Mohs hardness in the range of 5.0 to 5.5.

Obsidian's lack of crystalline structure causes it (much like ordinary glass) to fracture conchoidally, leaving a slippery smooth, undulating surface, and razor sharp edges—sharper than razors, actually. Flakes of obsidian have the sharpest edges known to science. The edge can be only molecules wide—as much as five times sharper than the finest steel surgical instruments. Once used by the American Indians for knives and arrowheads, obsidian flakes are now used in cardiac-surgery instruments because their extreme sharpness causes less

Figure 3.6: "Solitary Falcon, basalt, 9.5 x 8.5 x 11, 2013, by Tony Angel" (Photo courtesty of Foster/White Gallery.)

Figure 3.7: Two varieties of basalt are on the left, two varieties of diabase on the right. The stones are similar chemically, but diabase is grainier.

cell damage at the microscopic level, resulting in faster healing. Obsidian being a form of glass, the carving dust is inherently dangerous, and proper protection is required. Because it fractures like glass, it can only be carved by grinding. It is generally available only in small pieces.

3.3.3 Soapstone

Soapstone, also known as steatite (from the Greek word for fat), is an impure gray-green to black variety of the mineral talc. Pure talc has the distinction of being the the softest known mineral, and thus, has a Mohs hardness of 1.0. Baby powder is pure white talc. Because of its impurities, steatite is harder, having a Mohs hardness between 2.0 and 3.0 It is usually green, gray or white, but still has the slippery feel of baby powder. Soapstone is composed primarily of hydrated magnesium silicate, and is extremely easy to work.

Soapstone carvings can be treated with oil or left untreated. The material is not absorbent, and once oiled, tends not to stain easily. It is also resistant to heat, acid, and can be made into useful objects as well as sculpture. Bowls and other vessels, cook-tops, work surfaces for both kitchens and laboratories, and smoking pipes are all common uses. It holds heat and cold very well, which makes it useful in food preparation and serving.

It can be cut with a carpenters saw, hack saw, or coping saw, and can be carved with woodworker's tools, or even whittled with a pocket knife.

Because it is so easily worked with a rasp, soapstone is an ideal stone for young people, who can move up to edged tools and rotary tools, as their confidence develops.

3.3.4 Serpentine

Serpentine is a metamorphic rock, chemically related to soapstone, but more complex chemically and structurally, often occuring intermixed with other minerals. Strictly speaking, the rock should be called serpentinite, and the word serpentine reserved for the family of minerals of which sepentinite may be composed, but few other than geologists use the correct terminology.

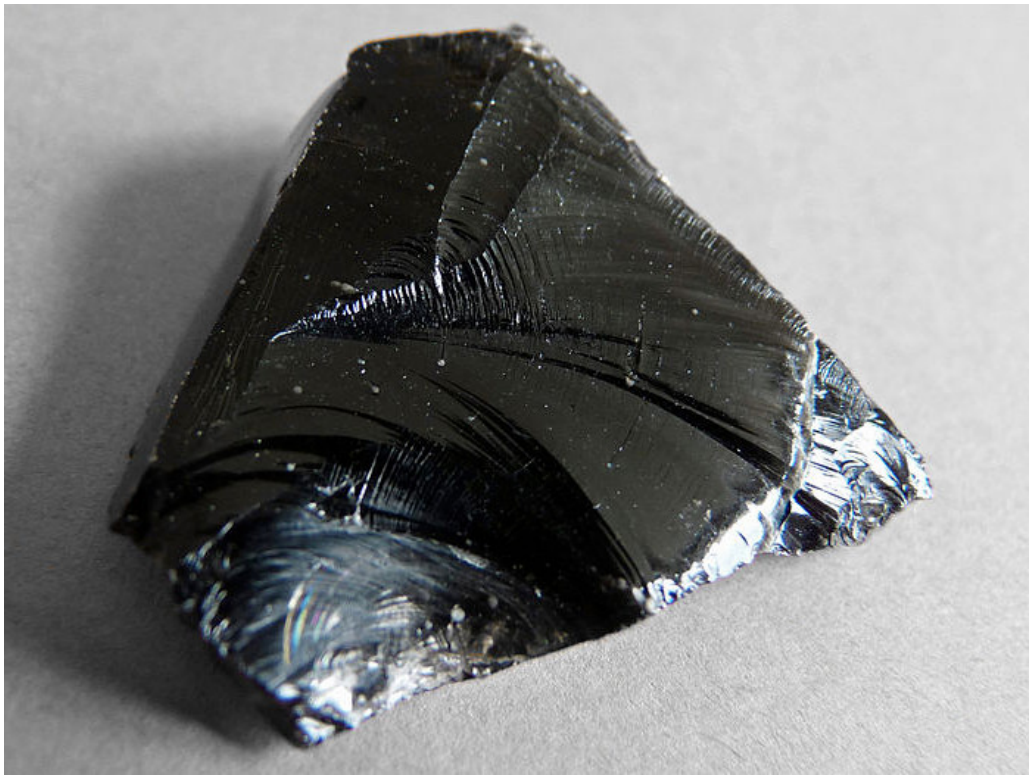

Figure 3.8: A typical chunk of obsidian (photo courtesy of Ji- Elle via French Wikipedia.)

Figure 3.9: A block of raw Italian soapstone for carving. The stone has been sanded to #220 and wetted.

Serpentine is harder than soapstone, but still easily worked, and is often sold for carving. Serpentine's Mohs hardness is usually around 3.0, which is too hard to be carved with a knife, but easily bushed, rasped, or chiseled. Old-fashioned square, so–called soapstone laundry sinks are usually made of serpentine, not soapstone. It is usually gray to green, and may be either partially translucent or opaque. Some varieties are fairly plain, and others have beautiful complex structure.

It is a common stone in many areas, but it's not a good idea to carve your local serpentine unless you are sure that it is free of asbestos, with which it often occurs. (Asbestos is one of the serpentine minerals.) The geology department of a local college may be able to help determine this.

3.3.5 Alabaster

More than one kind of stone goes by this name. The more common of the alabasters is a form of calcium sulphate, or gypsum—the raw material from which plaster of Paris and plaster-board (a.k.a. Sheetrock) are made. Chemically, it is $CaSO_4H_2O$, i.e., calcium sulphate with a water molecule chemically attached. This stone is translucent, almost transparent, and takes a high polish easily. It comes in a variety of colors, and many varieties are very beautiful, shot through with veins of color. It is among the softest stones, having a Mohs hardness 1.5 to 2.0—soft enough to whittle with a knife, and some varieties are soft enough to scratch with a fingernail.

Alabaster is mainly worked by rasping and grinding rather than with hammer and chisel due to the ease with which it bruises[4]

Various colors of alabaster can be purchased directly from quarries in the Western United States if you're willing to buy enough, or can be had in smaller quantities from sculpture supply houses.

Calcium sulphate alabaster is so pretty that using it sculpturally can be a challenge, as the intrinsic beauty of the stone tends to overpower the carving, and the translucence and veining can obscure detail. However, the softness of alabaster does make it less frustrating stone for beginners than marble or limestone. Alabaster is slightly water soluble and therefore does not weather well.

The other alabaster is a kind of calcite, which is a form of calcium carbonate, and is thus related to limestone and marble. Calcite alabaster is harder, app. Mohs 3.0. You can also tell which one you are dealing with by testing with hydrochloric acid. Calcite alabaster will foam, while gypsum alabaster is more or less unaffected.

Both kinds are mined in the United States. Gypsum alabaster is the variety more often sold for sculpture.

[4] A bruise is a milky area in which many invisibly small cracks cause a region of greater opacity in a stone. Bruises can be anywhere from millimeters to inches deep and are not removable.

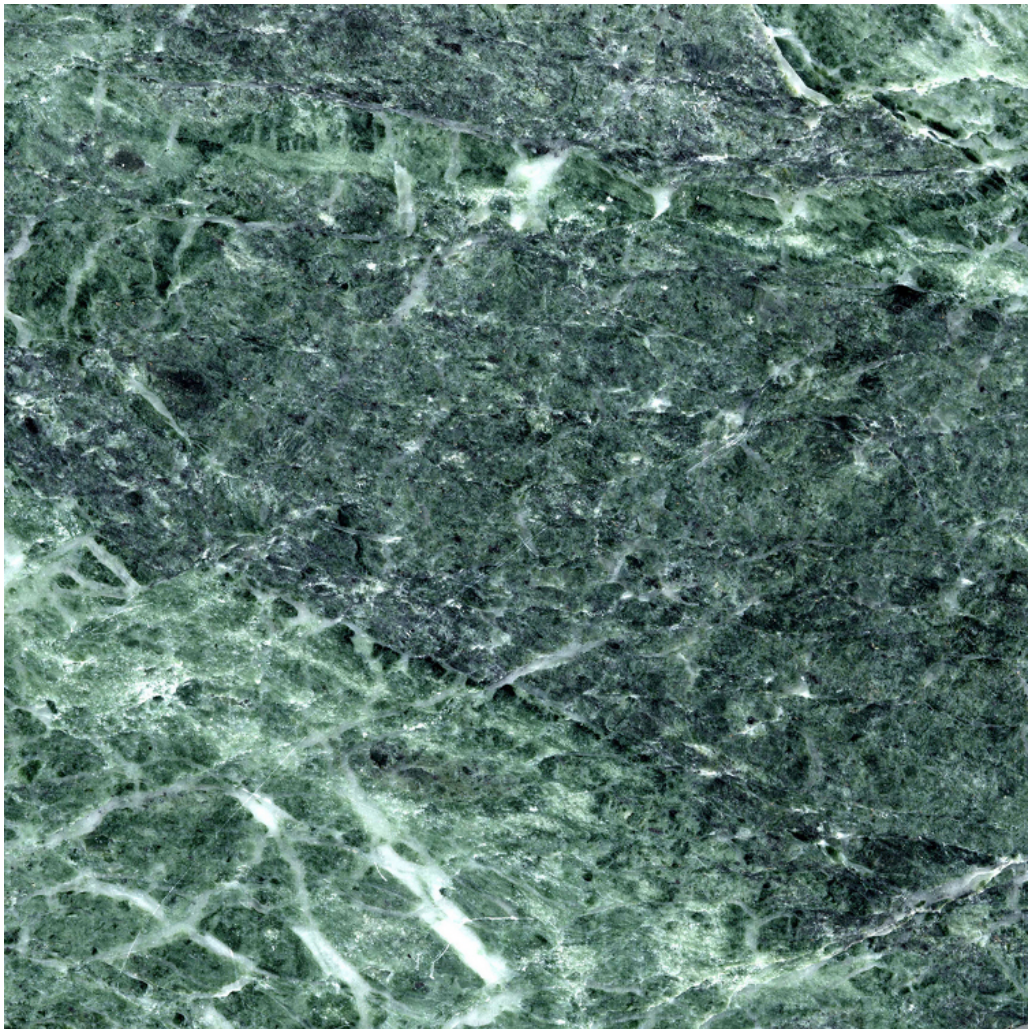

Figure 3.10: A closeup of a green serpentine (Photo courtesy of kevinzim/Kevin Walsh via Wikipedia.)

Figure 3.11: *Head of St. John the Baptist* 15th Century England, Alabaster (calcite), Victoria and Albert Museum

Anhydrite

Anhydrite is chemically similar to alabaster, being pure calcium sulphate, $CaSO_4$, without the attached water molecule present in alabaster. With a Mohs hardness of 3.0 tp 3.5, it is harder than alabaster, but softer than most varieties of limestone or marble. Colors range from white to dark brown, and it can be variegated like alabaster, but is usually less showy.

3.3.6 Sandstone

Sandstone is composed of sedimentary sand cemented together in a matrix of other minerals under the pressure of overlying deposits. Many forms of sandstone are carvable with the right tools. The sandstones vary widely in overall hardness, color and durability out of doors, but all are extremely abrasive due to the hard quartz sand.

Sandstones also vary widely in their ability to hold detail, due to their granular nature. The "brownstone" neighborhoods of New York and other cities in the Eastern US, dating from the latter half of the Nineteenth Century, are (or more accurately, were) mostly faced with Triassic-era sandstone from New Jersey and Connecticut, often extensively carved. These sandstones are composed of silica sand cemented with iron oxide, which gives it its distinctive brick-red color. The lack of resistance of this stone to weathering is evident from the ubiquity of the artfully applied stucco with which much of it has been re-faced in the last fifty years. How much varies from neighborhood to neighborhood, but in most areas, almost all the original sandstone has severely eroded and has been covered or removed.

There seem to be two main modes of erosion: sometimes the stone crumbles away from the surface, rounding off the details. More destructively, water gets into the stone, and cause it to swell like a book left out in the rain, exfoliating large flakes and chunks. Sandstone can withstand the elements for many years, seemingly impervious, then suddenly disintegrate in just a few years. The differences in erosion patterns may be caused by differences in the stone itself, the orientation of the carved stone with respect to it's bedding direction, subtleties of placement that result in better or worse drainage, more or less exposure to the sun, resulting differences in the freezing and thawing patterns, etc.

Sandstone is widely available, and in many areas is quarried locally. Beware of sandstone you find or quarry yourself, because if it's exposed enough for you to find it, it may be weathered to an upredictable depth. The hardness and durability of varies widely. Connecticut/New York/New Jersey brownstone weathers fairly quickly, but the sandstone sold in New York as "blue stone" is very durable; New York blue stone paving stones a century old seem almost unaffected by weathering, and many have withstood repeated resetting because of heaving by tree roots. The grainy nature of sandstone makes some varieties unsuitable for finely detailed carvings, but some varieties do hold detail, and can even be polished, such as the gray–green graywack sandstone carved by the Egyptians. Figure 3.13 is carved from a dense, fine–grained Egyptian

Figure 3.12: Carved sandstone ornamentation on a Manhattan brownstone, c.1885

sandstone, which unlike some sandstones, polishes and takes detail well. Note that hundreds of varieties of sandstone are called graywack, and many do not have the uniformity and other characteristics of the Egyptian stone.

Sand is silica, which means that you need to observe the lung-safety precautions covered elsewhere in this book, and it probably should not be carved in a home or schools studio. Whether hard or soft, the quartz content (Mohs 7) makes sandstone extremely abrasive, so tungsten carbide is usually used, as it will wear down steel tools very quickly.

3.3.7 Slate

Slate, familiar in the form of roofing shingles and blackboards, is metamorphic, originating as shale, a sedimentary rock which in turn originates as clay. It is found in several of the Northeastern states, and while usually encountered in sheets, can also be obtained in carvable blocks.

Slate is unsuitable for outdoor pieces because it weathers quickly, splitting into thin sheets. (The slate used for roofing always has the bedding direction parallel to the roof, so it does not absorb water. This would not be true of a block.) It is not carved with chisels due to its fragility, but like alabaster, can be sawn and ground. Slate typically has a Mohs hardness of about 3.5, similar to a soft limestone. The tendency to break into sheets is a good example of anisotropy, a property that is not captured by the Mohs scale.

Figure 3.13: Apollo with Lyre, graywack from Wadi Hammamat (Egypt), 1st

Figure 3.14: "Ravens Wall, slate, 48x18, 2007, by Tony Angel" (Photo courtesty of Foster/White Gallery.)

3.3.8 African Wonder Stone (Pyrophyllite)

African wonder stone, a form of the mineral pyrophyllite, is somewhat similar in it's working properties to soapstone, and is available from sculpture supply houses. Pyrophyllite (so named because it breaks into leaves on exposure to flame) do not have the silky touch of soapstone and talc, and is deader and more clay-like in appearance. Wonder Stone is a homogeneous, not very interesting dark gray, but it can be sealed to a silky, almost black finish. It carves very easily and is a good stone for beginners, but it generates a lot of dark gray dust.

Pyrophyllite occurs in many other colors as well and is found in a number of locations in the United States, but is not often encountered in raw form, being mined primarily for the ceramics industry and as a refractory material. It is harder than soapstone, and having a Mohs number of about 3.0, is soft enough to be sawn by hand or worked with a steel knife.

Figure 3.15: African wonder stone figure carved by Larry Ahvakana (Photo courtesty of Stonington Gallery.)

Chapter 4

Lifting and Handling

The density of materials can be given in pounds/cubic-foot, or kilograms/cubic-meter, but it is often expressed in terms of specific gravity, which is the factor by which a volume of the material is heavier or lighter than the same volume of water. This is handy, and particularly so when using metric measure, because the metric system uses water as the reference density for weight, with one cubic centimeter of water weighting one gram, one liter weighing a kilogram, and one cubic meter, weighing one metric ton. (A metric ton is 2,200 pounds, vs. 2,000 for an customary ton (cwt) in the US.) The specific gravity of the carvable stone ranges from about 2.4 to 3.0, i.e., a given volume of stone weighs a little less than three times as much as the same volume of water. Some stones are a little lighter, some a little heavier, and they vary even with categories, but you will not be far off if you estimate most stone, e.g., marble, limestone, and granite, at 2.7, and the iron rich, mafic stones, such as basalt and diabase, at 3.0. Water (and therefore, a person[1]) has a density of about 62 pounds per square foot, versus about $2.7x62 = 170$ pounds per cubic-foot for stone.

Using these facts, it is easy to estimate the weight of any rectangular block stone. The volume of a rectangular block of stone is length time width time height. If you measure in inches, you can convert to cubic feet by dividing this by the number of cubic inches in a cubic foot, 1,728, then multiply by the weight per cubic foot. If all you have is the specific gravity, multiply the volume in cubic feet, times 62, times the specific gravity.

A useful trick for smaller irregular stones is to compare it to a volume of water. For instance, a piece of stone the size of a gallon plastic jug of water will weigh about $8 * 3 = 24$ pounds. If it's the size a five pound roast beef, call it fifteen pounds. A cubic meter of stone will weigh about three times as much as a cubic meter of water—about 6,600 pounds, or three metric tons.

Even a small piece for a bust, say, three cubic feet, will thus weigh about

[1] Fat floats, while lean meat and bone sink. People of average build float when their lungs are full, and sink when they exhale, so their overall density is approximately equal to water. The obese float even if they exhale, particularly if they are not muscular, and ripped athletes have trouble floating at all.

510 pounds. How does an artist handle masses like that without a crew? It's actually not hard, with some lumber and a few basic tools. This section will give you a basic bag of tricks that can be used in many situations. Just remember Murphy's Law: *"If something can go wrong, then sooner or later it will go wrong,"* and don't be under or between heavy things when it does.

4.0.9 Moving Egyptian Style

If you have a strong floor, moving blocks of up to a ton or two around the room is easy, even when working alone. You need a crowbar, some pipes, and some scrap lumber. The process is illustrated in Figure 4.0.9

1. One person with a crowbar bar can easily tip a one-ton block. If you can't get the tip of your crowbar under the stone, try driving hardwood wedge under it to get that first fraction of an inch. A flat steel bar laid on the floor can serve as a fulcrum if the natural fulcrum of the tool is too far from the tip. (It's a good practice to routinely place stone and other heavy objects on wood slats rather than directly on the floor.) Shim up the opposite side as well before proceeding, because it will be harder to get the crowbar under later.

2. Crowbar it up enough so that you can kick a piece of scrap wood under the edge. **Important:** do not hold the board in such a way that your fingers are ever under it, because if you accidentally set the stone down you will crush your fingers.

3. Repeat, with thicker wood under both crowbar and block, until you have one edge of the block raised higher than the diameter of the pipes.

4. If the stone isn't too big, you can put the pipe near the middle, remove the wood, and teeter-totter it onto a second pipe. Be extremely careful doing this if there is any danger of getting your hands between the stone and anything else, such as the wall or another block.

5. If the stone is too heavy for that, lift the other side onto wood to the same height to get the entire block high enough for he pipes.

6. Slide the pipes under the stone about a quarter of the way in, then lift the stone enough so you can pull the wood out, and set it down on the pipes. It's better if they are not lined up parallel because this will reduce the tendency to roll. You can shift the pipes around later by hitting them with a mallet.

7. Once the stone is sitting on the pipes, you can either roll it in the obvious way, inserting a third pipe in front each time the stone gets close to rolling off, or you can skid the stone sideways in the direction of the pipes. The latter takes more work, but it's easier to control. If the stone is too heavy to simply push it along the pipes, shove a crowbar a few inches under it at a low angle and lift to shove it along.

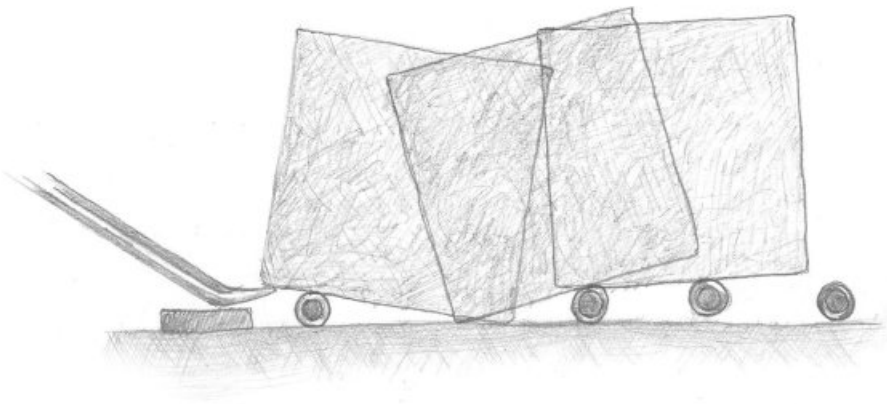

Figure 4.1: Moving a block on rolling pipes.

8. You can make a turn either by skidding the block onto a new set of pipes or by reorienting the pipes with the mallet.

A block on rollers can only get away from you for at most half its length, at which point the front will tip and wedge itself against the floor. The other pipe will be at the tipping point, so it's easy to tip it back up. You can limit the motion of the stone by putting either the crow bar or a piece of two-by-four against the floor at a sharp angle in front of the stone. With this technique you can control even a multi-ton stone.

You can easily punch a crowbar through the planks of a wood floor, even if the floor as a whole is plenty strong enough to hold the stone. If you working on a wooden floor, use a wooden plank to lever on. It should be perpendicular to the joists (which are usually at right angles to the direction of the floor boards) and long enough to span two of them.

If there is uncertainty that the floor is strong enough, a standard engineering manual (any library will have one) will give you the bearing strength of the floor based on the size of the joists, the distance they span, and their distance apart. If you are on a first floor, temporary columns from the basement floor to mid-span can to strengthen the floor enormously. Tubular steel columns with screws that allow them to extend to the exact height needed can be had at any lumber yard. Steel is only worth it for permanent installation; if it's just temporary, you can use 2x4's or 4x4's. You can cut a piece the width and depth of the joist out of a 4x4 and nail it to the joist, or you can use one 2x4 directly beneath the joist, with a longer one fastened to it, and to the side of the joist. Either makes

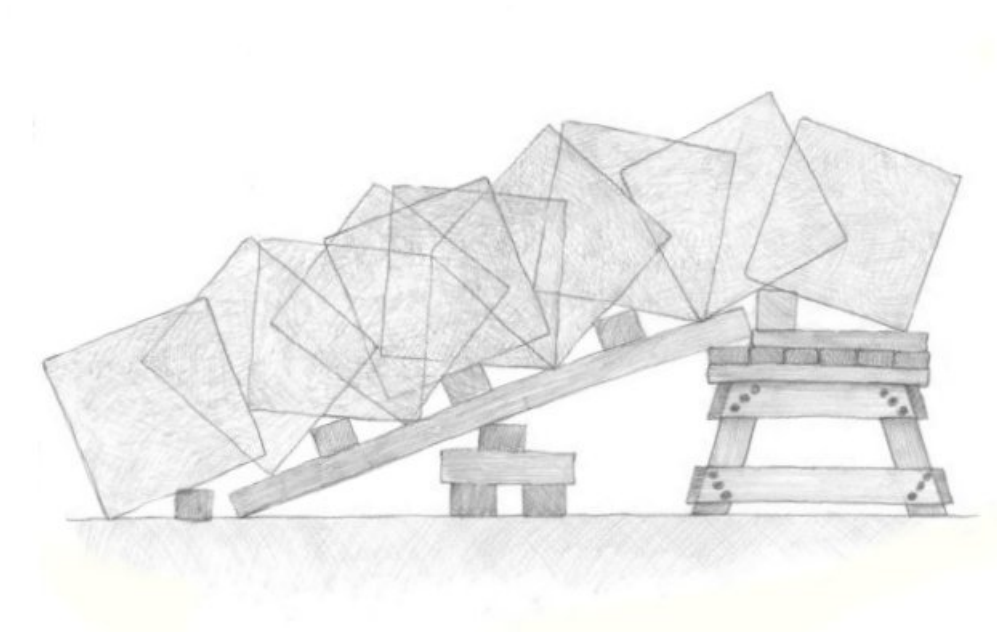

Figure 4.2: Rolling a heavy block up an incline.

a very strong post. Use a construction screw or a 10d nail every six inches to fasten the 2x4's together, plus two or three through the longer 2x4 and into the joist. If the post is not quite long enough, snug it up by driving two roofing shingles under it, from opposite sides, to wedge it more tightly. Another thing that makes a floor stronger is "bridging" between the joists. Bridging keeps joist under load from twisting, making them stronger. This should already be present, but if it is not, you can either buy and install ready–made steel bridging at the lumber yard, or simply fasten a 2x4 spanning across the joists from the underside, and screw it to each joist with three heavy construction screws.

Another consideration on a wooden floor is the strength of the flooring between the joists. For heavy stones, you should working with two-by lumber, perpendicular to the joists, under the load.

4.0.10 Rolling a Block

Now that you've got the block where you want it, you will want to lift it to a convenient height for working. The process is illustrated in Figure 4.0.10.

If you only need to lift a block a little, use the technique described above to lift it onto wooden blocks instead of pipes. Two-by-fours or four-by-fours can be laid across each other several layers deep. Toe nail the supporting lumber together for safety, so it won't shift when you move or turn the stone. A bed of 4x4's is good up to a foot or so. Rough 6x6 or 8x8 shoring lumber is good for

higher platforms, and very cheap.

If you want to get onto a higher bench than that, the following technique can be useful. You need a pair of heavy timbers to use as a ramp—old floor joists are great for this. The stiffness of wooden board is proportional to the width multiplied by the *cube* of its thickness, so thicker is a lot better. One plank probably isn't wide enough to use as a ramp, so fasten two together side-by-side by screwing wide pieces of plywood or strong lumber to the back. The two planks don't have to be touching— you can space them apart for greater stability.

One trick for getting the stone up the ramp is illustrated in Figure 4.2. You roll the stone up a ladder of blocks spaced so that as the stone rolls over a block, it is close to it's tipping point just as the leading edge touches the ramp. Try this out on with the planks flat on the ground before trying it on a ramp.

Whenever you're using a ramp, be very sure it is fastened securely to the trestle or work surface you intend to place the stone on, and be sure the entire construct is secure and immovable. Placing the trestle against the wall is ideal. Fasten the ramp the trestle or work surface with the soft iron strapping sold for hanging plumbing pipes. The strap is one inch wide, and comes in a roll, pre–perforated for bolts or screws. Screw it to the ramp and the table with construction screws or nail it with concrete-form nails (they have double heads to make them easy to pull out again when the form is dismantled.) This is not shown in the illustration.

If the block is too big to roll by hand, or does not have a square cross section, a come-along or block-and-tackle can be used to drag the block up the ramp by brute force. If the stone is not not too heavy, you can wrap the chains directly around the block on all sides, like tying a package, hook the come-along to the chains, and just drag it up the ramp right on the chains. Chain can be connected temporarily using carriage bolts, nuts, and heavy gauge washers. Use bolts that are at least as thick as the links.

A steel eye ring attached to the wall several feet above the workbench surface is a great permanent feature for the studio. If it's anchored with expanding anchors, it has to be placed so that the direction of pull on it will not be close to straight out, but at least partly from the side. The ring in my studio is attached to a 3/4 inch threaded rod that sticks out two inches, and extends through the wall, so that it cannot be loosened or pulled out from any direction.

For heavier blocks, you can make a temporary sled to drag it up the ramp on. If you can find a shipping pallet of the right size, you can just nail a piece of plywood to the bottom. Rub bar soap or bees wax on the bottom to grease it. Lash the block to the skid with rope or chain, and attach the winch hook directly to the lashing.

Be sure the work surface and the ramp are strong enough and cannot be pulled over. You can reinforce them with temporary 2x4 reinforcement if necessary.

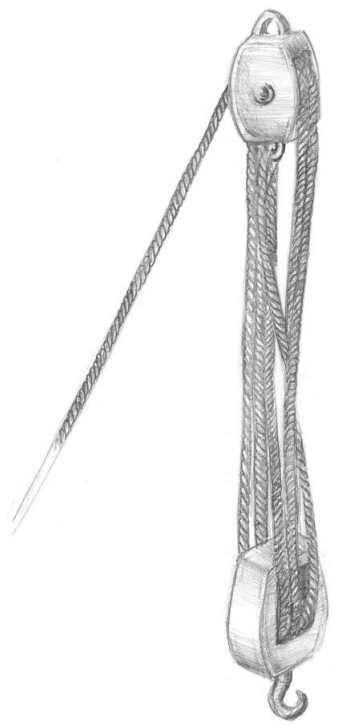

Figure 4.3: Block-and-tackle with a 5:1 mechanical advantage.

4.0.11 Block-and-Tackle

This traditional rig, seen in Figure 4.0.11 is useful for directly lifting moderate loads. It's a system of rope and pulleys that gives you mechanical advantage by exchanging distance for force. A rope over a single pulley gives no mechanical advantage, just a more convenient orientation of the lifting force. The block and tackle employs many loops of a single rope to draw two sets of pulleys together. To draw the pulleys together one unit of distance, you must pull one unit of rope for each of the lengths of rope that connect the pulleys, thereby increasing the pulling force in proportion.

A block-and-tackle is elegant, but they are cumbersome to operate and much more expensive than the alternative, a chain fall, but you might get one cheaply on craigslist or at a yard sale.

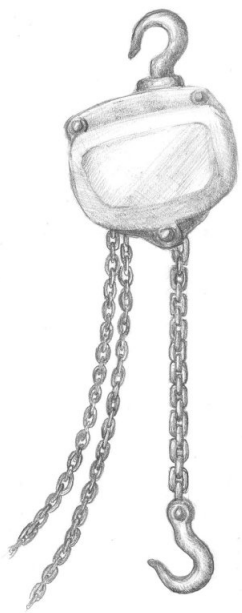

Figure 4.4: A typical small-capacity chain fall (one ton)

4.0.12 Chain Fall

A chain fall,illustrated in Figure 4.0.12 is similar to a block and tackle, but it works with chain instead of rope, and uses gearing, rather than pulleys to obtain mechanical advantage. They are typically hung up high, either rigged to roll along a beam or simply hung on a hook. They are rated at anywhere from five hundred pounds to several tons.

An extendable chain with a hook on the end hangs down from the metal block that houses the gearing. A manually operated chain fall has a second loop of chain that the operator pulls on to turn the gears. By pulling the loop of chain in one direction or the other, the hook can be slowly raised or lowered. They are also available with electric or pneumatic power instead of the loop of chain.

Unless your chain fall is mounted on rollers from an I-beam, you'll only be able to use it to lift stones onto and off of dollies and other rolling platforms.

Figure 4.5: A two-ton come-along.

Make sure the attachment is solid—a loop of chain around an existing beam is good. Fasten the loop of chain with appropriately sized bolt and washers. For heavy lifting, overhead beams can be temporarily shored with a metal columns or four-by-fours. And once again, stay back. Don't be anywhere where you can be hit by either the stone or the chainfall if something breaks.

4.0.13 Come-Along

A come-along, shown in Figure 4.0.13 is an inexpensive portable winch driven by a manually operated lever. There's a hook on one end for attaching the rig to some stationary object, and a long cable with a hook on the other. A lever is used to wind the cable in and out, and a system of pawls allows the cable to be ratcheted in either direction, depending upon how you set the control switch. They don't look like much, but even the lightest duty come-along will easily lift 1000 pounds, and the big ones are rated up to five tons. In the studio you can use them for dragging stones around the floor or up and down ramps, or for lifting stone directly onto a platform. Be very careful when using one to lift, because it's inherently hard to operate from a safe position. You need to be safely above the level of the stone. Also, be aware that the maximum rated load for lifting will be lower than for pulling. Also beware that a cable snapping under these kind of loads is dangerous in itself, apart from the unexpected release of the load, so do not exceed the rated load, and if the cables are worn, or the mechanism seems damaged, chuck it and buy an new one.

A two-ton come–along costs about forty or fifty dollars. Notice that the one pictured has an extra pully on the cable end hook that doubles the mechanical advantage. This feature does not appear on every come–along, but is nice to

Figure 4.6: A typical two-ton engine pulling crane.

have.

4.0.14 Engine Pulling Hoist

An engine hoist, show in Figure 4.0.14 is a small, lightweight hoist used by mechanics to lift engines from automobiles. Depending on the model, they're good for up to two tons and usually operate hydraulically. They have a lift a hook suspended from the end of an arm that's long enough to reach to the center of the engine compartment—plenty of distance to place a fairly large work block on a supporting structure. They have long feet to slide under the car or bench to keep the base beneath the hook. A new two-ton engine pulling crane costs about four hundred dollars, but you can often find them used on craigslist.com or eBay.

4.0.15 Hydraulic Work Stand

A hydraulic work stand is a fantastic studio accessory. The stand shown in Figure 4.0.15 will lift a thousand pounds to a working height of up to 36 inches. Prices for lift tables vary wildly for some reason. The one shown sells for three hundred dollars online. Very similar tables with the same rated capacity sell for as much as twenty-five hundred dollars.

4.0.16 Lazy Susan

A lazy Susan turntable with bearings is ok for modeling in clay, but it isn't good for carving stone. You really don't want hundreds of pounds of stone moving

Figure 4.7: A heavy-duty lift table.

too freely; it's dangerous and it makes it hard to work.

A better solution is to set the block on a round or octagonal piece of plywood, instead of directly on the bare bench. For up to a few hundred pounds, this will reduce the friction enough that you can shift the stone by hand. Soaping the bench top, or rubbing bee's wax on it first will reduce the friction further. Formica, melamine, or masonite, laminated to the side facing the bench, reduces the friction much further, but be careful, as it can reduce the friction to to the point of being dangerous.

A large screw or lag bolt, through the center of the plywood and into the bench will constrain the motion to rotation, making it much safer. A C-clamp can be used to lock the turntable in position while you are working.

4.0.17 Cradles

Cradles, an example for small pieces is shown in Figure 4.0.17, are good for holding work in the right position. This one has plank sides and hardwood slats, make working on pieces at odd angles easier. Two-by-ten fir or pine off-cuts make good sides. Great stock for slats can be had from the discarded futon bed frames that people are always throwing out.

For larger pieces, nail a cradele together out of 2x3 hemlock or fir. If the front edge projects downward half an inch or so, it can be allowed to hang over the front of the work bench to prevent the workpiece from sliding to the back of the bench.

Alternatively, pairs of holes drilled on each side to allow 1/2" bolts to drop through will allow any of the sides to catch the front of the bench.

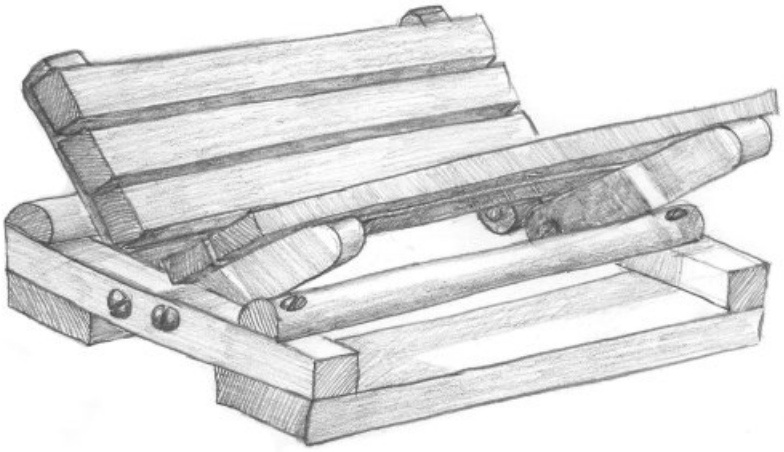

Figure 4.8: An adjustable wooden cradle

4.0.18 Sand Bags

Sand bags are useful for blocking up a piece in progress. For small bags, sections of the legs from old blue-jeans can be sewn into sacks. Lumber yards sell sand in fifty-pound plastic fiber sacks that are sturdy enough to use as is if you need bigger bags. These are the same kind of bags used to make temporary flood walls. The same bags are usually sold empty as well, for about a dollar apiece, and are good for smaller sizes. The soft iron wire used for tying concrete reinforcing rods is the best thing for tying them closed.

4.0.19 Dropping a Stone

Sometimes there is no good way to lift a heavy stone down from a truck bed. Perhaps there was a loading dock or forklift where you picked it up, and now you have a thousand pound block in the truck with no way to get it off. Simply pushing it off the back of the truck is not out of the question, if you pad the landing. In quarries, piles of dirt or sand are used to catch the huge blocks as they are split from the living rock. If you do have to drop a stone off the back of a truck, you can similarly cushion the landing with a wooden pallet or other old junk.

Block the pallet up well off the ground with a couple of 2x4's or 4x4's laid flat under two outer edges, to give it room to flex on impact. Arrange it so the pallet or pallets are supported from the ends of the main structural members,

Figure 4.9: A one dollar sandbag from the lumberyard.

and the weight will land across them, so there will be lots of flex. The wood will probably break—that's fine, the bending and breaking soak up the energy of impact. If the stone is very heavy or will drop far, use two pallets, with spacing between them as well as on the ground. You can also lay a thick stack of corrugated cardboard on top to further cushion it.

You can also make a landing pad with several inches of flattened corrugated cardboard boxes, or other crushable material, laid directly on the concrete, with a piece of plywood on top to spread the weight, and prevent the impact scattering the padding, or the stone penetrating to the concrete. Several styrofoam swimming pool noodles in a tic–tac–toe grid, with a piece of plywood on top, can absorb a very large impact.

Beware of padding that can bounce, such as tires—padding that crushes is safer, both when you drop, and later when you take the stone off the padding.

With everyone well back, tie a rope around the block, and if possible, fix the end to something solid, then drive the truck away. Moving the truck, rather than the stone, is safer for the truck, as the truck is farther from the impact, and the rope helps to control any tendency to roll toward the vehicle. The stone can roll, and wood can fly, so stay well back.

Also, be very careful of uncontrolled tipping or rolling of the stone when getting it down from the landing pad. Only drop stones that have a compact shape. Long pieces and slabs can snap even if they are quite thick.

Chapter 5

Dividing Stones

If you want to divide up a big block or save a waste chunk of your work-piece that's large enough to be useful, there are several options: the stone can be sawn, split with a pitching tool or tracing tool, or split with wedges.

5.1 Sawing

Sawing stone in the studio is usually done with a circular saw, using a diamond or abrasive disk. Before you even consider sawing stone, understand that unless you have wet-sawing equipment, the operator experience is pretty much like slowly pouring a sack of plaster into an electric fan.

Masonry cutoff saws look something like an angle grinder, but are configured for sawing. A heavy duty angle grinder may be used if has the proper shielding for cutting. In a pinch, an ordinary carpenter's circular saw can be used for cutting a slab, but the size of the wheel that can be used is limited to under eight inches in diameter. The nominal size is misleading—an eight inch wheel has only a four inch radius, less the thickness of the machinery for driving it, leaving an acutal cutting depth of only a couple of inches. A heavy-duty 16-inch cutoff saw with a diamond wheel can be rented for about $60 per day. Gas and electric varieties are available.

The gear housing on a masonry saw also uses up a lot of the potential depth of cut, but these tools can accommodate big wheels. Even so, a 14 inch cutoff saw only has at most a four-inch depth of cut. The limited depth of cut may not be as bad as it sounds, because it is not always necessary to cut all the way through the stone. Often, the stone can be cut deeply from both sides and then broken the rest of the way.

With the right wheel, these saws will cut through any kind of stone. Diamond wheels are what you want for stone, but you can also use abrasive wheels made of hard fiber with silicon carbide particles embedded. Diamond wheels are metal with a crust of diamonds. Whatever kind of wheel you use, make multiple shallow passes, increasing the depth each time.

There are also more exotic (and more expensive) masonry saws that cut much deeper. These devices can usually be rented.

- Masonry chain saws with diamond-encrusted chains are used commercially to cut reinforced concrete, brick and block walls, cement pipe, etc., and can cut through up to 15 inches of marble or limestone, but are not for use on granite. They can be powered by gasoline, electricity, or hydraulic power, and work pretty much like a regular chain saw, allowing both cutoff sawing and "plunge" cutting, in which the saw cuts into the block tip-first, which allows either open or blind holes to be cut. A water-hose hookup keeps the blade cool and clear of chips. These things are simply amazing, but they are a big-ticket item, with the contractor–grade models costing about $2000, and replacement chains about $500. Industrial-grade saws are considerably more expensive, usually run by hydraulic power, and require a gasoline—powered portable power supply. Power supplies are typically about the size of an exterior central air conditioner and cost upwards of $5000.

- Sixteen inch circular saws, with eccentric blades that are turned from the edge, rather than from a hole in the center, can cut almost as deep as a chain saw (14 inches) but the minimum width of the cut is determined by width of the blade at that depth, so this tool would be mainly useful for cutoff work, not for plunge-cutting. These saws are hydraulic powered, and use diamond wheels that work on granite, or any other hard material. These are industrial–grade equipment: they cost well over $2000, not including blades or the hydraulic power supply (see above.)

- For extremely large cuts, stationary wire saws have a more or less unlimited depth of cut. Wire saws are usually fixed to a trailer, which is parked in front of, or even on top of, the work piece. These saws use a diamond-encrusted cable, which can be of any length. The cable is looped around the block to be cut, and the saw continuously pulls on the cable while maintaining steady pressure. With some cable saws, the cable can be fed through holes drilled in the work block, allowing pieces to be cut out of a the middle of a large block. For complex situations, auxiliary pulleys can be used to steer the cable around corners, etc. This is a major industrial tool that artists would be more likely to rent than to buy. Huge versions of these saws are used in quarries.

When sawing with a grinder or cutoff saw, you must match the RPM rating of the disk to the speed of the saw. Each disk has a design limit at which it can be safely operated due to the centrifugal force generated by the spin, and the drag from contact with the work piece. Some of these saws have water fittings, and some of these can run either wet or dry. Wet is much better if it is practical to use in your studio.

5.2 Splitting With Chisels

If a stone is not too large, it can often be divided using a heavy chisel called a tracing tool, or with a splitting hammer, which is really just an oversized tracing tool on a stick. Stone masons do this routinely, sculptors less so, because of the risk wasting stone with a bad break. The main advantage of splitting over sawing or wedges, is that it leaves a raw stone face will be unmarked by the saw or drill. Thus, it might be preferred for making bases, or in cases where part of the block will be left uncarved. This kind of splitting works very well with hard stone such as granite.

A tracing tool is used to score a line into the stone, preferably all the way around the block, by progressively harder blows on the intended cut line, until the bottom of the traced like is continuous, and not broken by irregularities in the stone surface. After the cut is fully "traced," the tool is placed the traced groove in the middle of the block and hit hard, with a heavy hammer, to split the block. The cut must be far from an edge, preferably in the middle of the block; if it is too close to one side, the break will often head off in that direction.

Sedementary and metamorphic stones, usually retain a memory of the layering of original sediment layers. The direction in which these layers lie is called the bedding. The stone separates more easily in the bedding direction, so it is important to break either with the bedding or perpendicularly to it. Attempting a break at any other angle will rarely give the desired result.

Despite their appearance, which seems uniform in every direction, many igneous stones also often also have a direction in which they split most easily, known as the "rift." They may also have a secondary direction in which they split more easily, usually perpendicular to the rift, and known as the grain. These properties may be caused by the shrinkage of the stone as it cools, with the cooler side being up, and the hotter side being down, and with plutonic rock, from the release of the enormous pressures found miles below the surface. The rift usually corresponds to the vertical direction in the earth, and the grain to the horizontal.

The tracing tool can be used to split even very hard stone, but it can be damaged by using it on a non-flat surface, because uneven contact puts too much strain on the edge. This is particulaly a risk with carbide edged tools. If you must splitting from an unsawed face, the traced line must be made gradually with light taps, until a continuous straight edge is reached. When the bottom of the traced line has become a continuous line the tool can be hit harder.

For large blocks, a splitting hammer can be used in place of a tracing tool, with one worker holding the hammer head in place, and the other hitting it with a maul. The splitting hammer is normally used to trace the line, but a tracing tool can be used first, and the splitting hammer reserved for the break. As with the tracing tool, increasingly solid blows are used along the line of the split, then a final heavy blow in the middle divides the stone. The splitting hammer is primarily a mason's tool, and would rarely be used by a sculptor.

In some varieties of stone, the grain in the direction the bedding is so pronounced that the tone cane be split into thin sheets using wedges. When break-

ing such stones in the bedding direction, no holes are drilled. Instead, sharp wedges are driven directly into the stone, and the resultig crack is propagated across the stone by following along it, inserting more wedges. Stones that can be split this way are usually sedementary, such as slate, and some varieties of limestone.

Many variations on this kind of splitting exist for different kinds of rock, Most of these techniques are used more by builders and stone masons than by artists.

5.3 Splitting With Wedges

Splitting with wedges is faster and easier way to divide a block than sawing, and can be used even on enormous blocks or boulders. With a roto–hammer, wedges, and three-pound engineer's hammer, a single person can easily split a stone the size of a Dodge van. Use of this method goes back to ancient times, and it is still widely used.

The basic technique is very simple:

- A carbide-tipped drill is used to make a row of holes along the line on which the block is to be divided. It is not normally necessary to go all the way through the stone.
- A pair of steel "feathers" are inserted into each hole, and a wedge inserted between each pair of feathers. The feathers are metal shims, round to match the hole on one side, and flat on the other. They partly fill the hole, and provide firm surfaces for the outward pressure of the wedges to bear upon. You want a the pressure diffused so you don't start cracks in the wrong direction.
- Be sure the wedges are pressing out, perpendicular to the intended break.
- The wedges are tapped with a hammer, one after another, round-robin, building up pressure evenly.
- Get the wedges all solidly in, then give it a rest for a few minutes.
- Repeat tapping and resting until the stone suddenly divides on the line of the holes. It does not take a lot of force to divide a stone.

When drilling the holes, clear the hole frequently by withdrawing the drill as it goes deeper, so that the waste does not become impacted and cause overheating of the bit or the drill itself. As always with carbide, do not use water or other coolant.

A rotohammer can drill a very deep hole in minutes, but in most cases, you actually do not want the holes to be deeper than is necessary to accommodate the feathers and wedge. The reason is that a hole can act as a barrier to the propagation of a crack. This is because a crack that reaches the hole on one

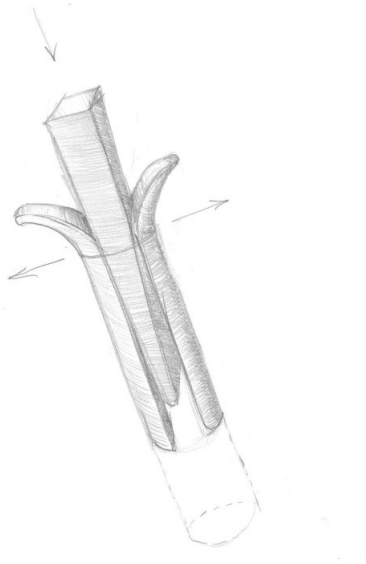

Figure 5.1: Feather and wedge placement.

side has to re-start on the smooth opposite wall, and it takes much less force to propagate a crack than to start one. Moreover, each time the crack has to re-start, it has a chance of starting off in some undesired direction. If the holes are shallow, the propagating crack can easily run under them and continue in the desired plan.

One reason to make an exception to this is if a stone has to be divided in a direction you are not confident about. In such a case, it can make sense to drill all the way through, but to drill so many holes that they do actually weaken the stone enough to make up for their crack-blocking ability. If this is the strategy, drill them close together and use a tracing tool or heavy chisel to score a deep line along the axis of the holes before applying pressure with the wedges.

Feather-and-wedge sets come in a wide range of sizes, for holes ranging from three eights of an inch to an inch and a half. Half inch is a good size for most studo applications. Increase the force of the blows slowly to build expansive force uniformly across the line of holes. Align the wedges so the expansion is across the intended break. Figure 5.2 shows the crack propagating across the stone. The feathers should start out as deep in the hole as they will go, If you are using the right sized drill, the amount of wedge sticking out will be correct. The drill hole should always be correct for the feathers, because with the wrong size hole, the feathers will not diffuse the pressure as well, increasing the chance of a crack going off in the wrong direction. You *can* safely use the wrong sized wedge if necessary, by shimming out with a piece of steel. Don't just tap

Figure 5.2: The split propagating.

each wedge the same number of times; listen to the pinging sound they make to gauge the pressure. The pinging will change tone as the crack starts—if there is a sudden deadness to the tone the break has started; move to another wedge. You can break even a huge stone without swinging the hammer very hard. The 3/8 inch wedges illustrated below required about an eight inch swing with a two-pound hammer to break the stone.

Notice that the line of wedges stops short of the edge at the bottom of the picture. This is because there is very little stone behind the break line on the left side. A wedge there might result in damaging that end of the off-cut. The after view of the break shown in Figure 5.3.1 show how shallow the holes were.

Before deciding on where to split, inspect the stone very carefully. Sedimentary and metamorphic stones often have a visible "bedding" direction—the natural grain of the stone as defined by the original sedimentation. Stone cleaves easily in parallel to the bedding direction. It also tends split predictably perpendicularly to the bedding. Attempting to split stone at intermediate angles leads to disaster, because because the line of the break will try to jump to follow the bedding, instead of following the plane defined by the holes.

Normally, you only need a wedge ever six inches or so, but if the stone is sketchy, you can use closely spaced, deep holes to remove a lot of stone. If you are using a lot of drilling to weaken the stone, one thing never to do is to also drill from the side. It seems like it would be a way to remove more stone, but it has the effect of stopping the propagation of cracks, making the stone harder to split, and giving the break more chances to wander off course.

Figure 5.3 shows a stone with a successful break on the right, and a disastrous break on the left. It's easy to see part of what went wrong: the the direction of bedding is clearly visible by the plane on the top and the parallel plane visible at the lower left, with a large hole penetrating it. The intended cut jumped repeatedly to bedding planes. Notice that the successful break is exactly perpendicular to the bedding direction. Note also that the bedding planes are neither parallel nor perpendicular to the sides of original sides of the block, which are the top and bottom.

Breaking with wedges can be used with stones of almost any size, and works on hard or soft stone. This technique is often used when clearing ground or excavating, to break up boulders.

The ancients quarried huge blocks for construction and statuary using wedges, often in combination with chiseling. The piece to be quarried would be undercut with chisels, then split off using wedges. Marks from this procedure can still be seen in ancient quarries. Plugs of olive heartwood were sometimes substituted for metal wedges. The dry plugs were hammered in tightly into a row of holes or into natural cracks in the stone, and water poured over them until the swelling of the wood burst the stone. An interesting modern version of this is called *Dexpan*® which is a cement-based powder that is mixed into a slurry and poured into pre-drilled holes. As the slurry sets, it expands, cracking the stone after about 24 hours.

When breaking large stones, be sure to place lumber and/or lifting chain before the pieces fall, as it may be difficult to get it under the stone later.

Figure 5.3: A bad break on the left and a good break on the right.

Sometimes it is useful to tie rope or chain around the stone before splitting it, to control the motion of the split pieces, particularly if one cannot be sure which piece or pieces will fall over.

5.3.1 Flaws

Stones often have visible flaws and veins that affect the strength of the stone that will influence the line on which it wants to split.

The left side break, shown in Figure 5.3 is like a museum of bad splitting. Not only was the bedding direction ignored, but a visible crack went unnoticed which would have resulted in a subsequent carving disaster even if the break had worked as planned.

Figure 5.3.1 shows a close up of the wildly-off split shown in Figure 5.3 There is a narrow region of dirt and green algae on the edge extending down from the point where the three planes of the stone come together indicating that a crack had long been present there. The crack can be seen to continue towards the upper left through the unbroken region on the original outside of the stone. This type of flaw, even if algae does not give it away, can often be spotted by spraying the stone with water. Flaws are revealed as lines where the water is sucked into the crack. Tapping with a hammer can also be a clue—just as you can hear that a kitchen bowl or a plate has a crack, by the dead sound, you can often detect a crack in a block of stone.

5.3.2 Combining Sawing and Wedging

There are times when a block is too thick to saw through, yet breaking with feathers and wedges isn't the ideal choice either. For instance, if the break plane is intended to be the flat bottom of a piece, then, between the diameter of the holes, and the wavering face of the break, you may have to remove a significant amount of stone to flatten the break plane. Another reason you may want to saw is that you are not confident of how cleanly the stone will break, either because you cannot ascertain the direction of the bedding, or because experience tells you not to expect nice straight breaks with this type of stone.

A large saw, cutting from both sides, will not achieve more than a total of eight or ten inches of cut depth. However, even if cutting from both sides will leave several inches of uncut stone, sawing can still allow you to finesse this situation. You can cut all the way around the block as deeply as your saw allows, then break the core of uncut stone in the middle by wedging.

The narrow wedges made for use with feathers are not right for this job—they may simply dig into softer stone without spreading it, and they are prone to damage, especially on hard stone, because they won't have the protective supporting sheath of the feathers.

A wide mason's chisel with a tapering blade makes a perfect wedge for this job. (Some mason's chisels have blades that are parallel, except for the beveled edge. You can use such a chisel, but it should be ground to a taper first, as described below.) Mason's chisels only cost about ten dollars new, and are easy

Figure 5.4: This flaw would have been plainly visible before the split was attempted. It extends from the point where the planes on the right come together, upward and to the left. A second flaw is visible branching perpendicularly from the first toward the upper right. The faint tinge of green algae indicates a crack that can hold water *and* exposure to the elements.

Figure 5.5: A clean break.

to find at flea markets. If you are dividing a large block, and need several wedges, you can make them from 1.5 or 2.0 inch by 1/4 inch steel bar stock. Grind the taper with a silicon carbide cup stone mounted on an angle grinder. Use a hacksaw to cut the wedge off the bar, and repeat, until you have enough wedges. If you are grinding down chisels for this purpose, beware that the heat of grinding will probably burn the steel, ruining them for use as chisels.

To break the stone, raise it up on a supporting strip of wood placed directly under the cut on the bottom, so that the weight of the block will work in your favor. Strike your chisels or wedges into the saw kerf, tapping gently at first, and building up the force slowly, as you would using the feather-and-wedge method. Wedge only above the core of uncut stone, not close to the sides, as this risks breaking off chunks. The wedges may crumble the stone at the edge—this is expected—but the wedges will quickly seat against the deeper stone. If your wedges are too thin, shim them out with strips of galvinized sheet metal, aluminum flashing, or any similar material, bent into an **L** shape, and hung over the side of the kerf.

If the stone does not break right away, get the wedges in tightly enough that they ring when struck, then give it some time before hitting them again. Repeat until the stone breaks.

Chapter 6

Manual Carving Tools

As mentioned above, most of the common sculptor's hand tools are ancient. In this section we look at these traditional tools for working stone and minor modern variations on them, such as the tungsten carbide tipped versions. Where it matters, the use of tools on soft and hard stones will be distinguished. Specialized tools for lifting, moving, and cutting stone are discussed in section *Lifting and Handling,* Chapter 4, and in *Dividing,* Chapter 5.

6.1 Carbide vs. Steel

Ultra hard tungsten carbide and similar "hard-metals" became widely available in the 1930's, and quickly revolutionized most technologies that required cutting hard or abrasive materials. Until the invention of these alloys, hardened steel was the only practical material for sculptor's tools, and the forging and maintaining of carving tools was an important part of a sculptor's training. Tools needed to be repaired or replaced frequently, and a sculptor needed to know how to forge and grind tools, and how to harden and temper them to suit the material at hand.

Tungsten carbide is not exactly a metal itself, but one of two similar metal-like compounds of tungsten and carbon (tungsten carbide, WC or tungsten semicarbide, W_2C) that are produced industrially as fine gray powders. The powdered tungsten carbide is sintered in a matrix of cobalt metal (sintering is an alloying process in which finely powdered metals are fused together by extreme pressure, rather than by being melted into a true solution.) Tungsten carbide prepared in this way is the hardest metal-like material in common use. Only certain gemstones and silicon carbide (*Carborundum*) are harder, and unlike tungsten carbide, those materials can only be used in the form of abrasives, not as cutting edges.

Carbide tools are somewhat more expensive to buy, but cheap in the long run, as they outlast steel by as much as a hundred times over, and allow you to work hard materials in ways that would otherwise be difficult or impossible. They

also require far less frequent maintenance, and the maintenance they require is generally simpler. For industrial use, carbide tipped tools have almost entirely replaced steel for cutting hard or abrasive materials like stone, as well as for many less abrasive materials like wood. However, in stone carving, carbide is not always an exact substitute for steel. Carbide is more brittle than steel, and cannot be ground to as acute an angle without becoming excessively breakable. This limitation gives many carbide tools a significantly different, working feel than their steel counterparts. For granite and similar stones carbide the way to go in virtually every case, but for softer stones, for many of tools, the sharper cutting angles that steel permits give deeper penetration and a better result, more easily, for many applications.

Steel tools are usually forged from a single piece of steel, with the business end being hardened by heat treatment, and the rest left in a softer, annealed state. Carbide-tipped tools, on the other hand, typically consist of a mild-steel tool body tipped with a tungsten carbide insert, or inserts, attached by brazing, i.e., soldered using brass. For chisels and similar tools, the carbide is usually set into a notch or drilled hole in the steel body of the tool.

Carbide is darker than steel, and the brass joint line between carbide and steel is usually visible, so carbide tools are easy to recognize. When these tools fail, it is usually either at this brazed joint or by shattering of the tip itself. Either mode of failure may or may not be repairable, depending upon the manufacturer and the cost of the tool. Small carbide burrs for grinders are sometimes machined from a single piece of carbide.

When grinding steel cutting edges on a wheel, it is important to keep them cool by quenching frequently in water or oil, and limiting the time they are in contact with the wheel. This is because the temper of the steel begins to change at as little as 425 degrees Fahrenheit, making it is easy for the heat of friction to "burn" the tip, leaving it uselessly soft. If, when grinding, you can see the metal near the tip change color (not glow, but actually turn yellow, blue, or purple) you have removed some or all of the effects of prior hardening.) It is more or less impossible to burn the steell when sharpening a tool by hand on a whet stone, which can also be more convenient for touching them up while you work. Wheels that run wet also obviate this danger.

With carbide, it is exactly the opposite: quenching while grinding can ruin the tool. This is because while heat does not temper the hardness of out of carbide, its extreme hardness makes it prone to being shocked by abrupt temperature changes. All materials expand or contract in response to temperature change, so when any hot tool tip is dunked in water, the wave of cooling moving through it causes adjacent regions of the metal to struggle against each other as they change size at different times. This does not affect high-carbon steel, because it is slightly elastic, but carbide is so rigid that these stresses can cause internal fractures to form, weakening it, just as a wine glass can break if it is dunked in hot water. Fortunately, most carbide can withstand very high temperatures. Multi-purpose carbide drills will bore through any combination of thick steel, concrete, plaster, and pretty much anything else, even granite, without the need for a liquid coolant.

Figure 6.1: Club hammer, lump hammer, engineer's hammer, round mallet.

It's actually easier to regrind carbide than it is to regrind steel, because you can do it continuously without overheating it, but there is one gotcha. Grinding with a fine silicon carbide wheel should be followed by polishing with a fine diamond hone. Carbide is somewhat like glass, in that it tends to break more easily where it is scratched. Polishing denies cracks a place to start, making the tip stronger. For the same reason, use the diamond hone to put a very slight champfer on the sharp edges, and to likewise take the corners off the ends. The tool will not be quite as sharp initially, but the chamfer leaves no razor edge to crumble and cause roughness that would give cracks a place to start.

When sharpening stone carving tools that have an edge, do not hone the edge to a mirror finish as you would with a tool for cutting wood; the edge left by a fine grind stone is good enough. A very fine edge will crumble or roll over immediately, leaving the tool less sharp than if the edge were left raw.

6.2 Traditional Hand Tools

6.2.1 Hammers and Mallets

Hammers for stone carving come in a variety of shapes and sizes. The traditional sculptor's hammer, called a **square hammer or club hammer** , is just a rectangular block of steel with a short handle. This is the default hammer you'll be handed in a sculpture supply shop. It's main virtue is that it looks very traditional. A more polished looking version, also with a short handle, is known as a lump hammer. **Lump hammers** are used in the trades for driving cold-chisels, masonry nails, etc, and thus tend to be mostly available in heavier weights. See Figure 6.2.1 for comparison.

Engineer's Hammers look like miniature sledge hammers and have longer handles than club hammers. They are not good for general carving, but come in handy for special purposes such as driving wedges to split stone.

Round mallets, are tapered cylinders of steel with short wooden handles.

Hammer choice is a matter of personal taste, but the round mallet has a lot of advantages for all-around carving. They're comfortable, pretty, and the compact design makes it easy to hold in a position that minimizes repetitive strain. These come in several sizes from one to three pounds.

A one or two pound hammer is good for general carving. How you swing varies with the task. Driving a pitching tool takes a healthy swing with a heavier hammer such as an engineer's hammer—two and a half to three pounds is typical. Finer carving can be done with small taps of a one pound mallet using a swing of a couple of inches.

How you hold your arm and hand is very important, especially on the back swing, Even when making light taps, try to move the elbow and shoulder rather than the wrist—you get much more power and better control. Carving requires swinging the hammer much more often than work in the building trades, so even if you are used to using a hammer, it's easy to develop a repetitive stress injury to the big tendon on the back of the wrist. This is caused by lifting the hammer improperly on the return stroke. When drawing back the hammer, hold it so that the the thumb side of the wrist, and not the back side, holds the weight of the hammer. In other words, don't pronate the wrist when pulling back the hammer. Your wrist is much stronger in this direction. If your position makes this difficult, for instance, because you're hammering vertically down, try lowering the workpiece, or standing on a platform to get your body higher relative to the point of impact.

It's easier to increase the force you're applying by speeding up the hammer head than by using a heavier hammer. Even holding the hammer just a littler further from the head adds a lot of energy over the duration of the swing.

One important class of mallets are those which have non-metalic surfaces: either wood, plastic, or stacked leather. Wooden mallets tend to spliter and break quickly when used on steel tools, but are can be used with socketed chisels that have wooden handles. Also, metal hammers will quickly ruin wooden handles. Wooden handled stone carving tools are unusual in the United Staties, but are still used in Europe for softer stone.

Mallets made of plastic or stacked leather soften the impact, and are said to less tiring than metal. Chisels intended for use with these mallets have distinctive wide heads, shaped like mushroom caps to spread the force, so as not to tear up the mallet faces. Conversely, these chisels should not be used with steel hammers or mallets, because the heads are often hardened to retain their shape, and will fragment rather than deform.

"Dead blow" hammers, can be made of either metal or plastic, and also tend to be easier on the user because the hit harder for their weight. These hammers are hollow, and contain several ounces of metal shot, which absorbs much of the bounce, resulting in more energy being delivered to the tool, and less to the user's arm.

6.2.2 Punches

The punch, or point-chisel is the workhorse of stone carving. A punch is just a metal rod, sharpened and hardened at one end, and left flat on the other (striking) end.

For marble and other medium-hardness stones, the cross section of the sharp end is usually square, with the four flat sides coming together in a gentle curve. The curve has two purposes: the sides come together at a relatively wide angle behind the tip, which makes it stronger where it is under the most stress, while slightly further back, where strength is not so much of an issue, the punch has less curve. The taper lets it go slightly deeper in the stone before the width bursts the stone, the deeper the penetration, the wider the chip. A corollary to

Figure 6.2: Carbide-tipped punch (left) Steel punch (right)

this is that the lower the angle, the more mechanical advantage in the sideways pressure.

For granite and other hard stones, punches are usually tungsten-carbide tipped. These punches have stockier shafts with a tip ground to a wider angle. Use of the punch on hard stone does not rely on penetration in the same way that it does on marble and limestone, but rather, tends to be used for knocking off bumps and corners. When used straight in, they tend to crush more than penetrate. Thus, carbide punces work best on hard stones but tend to work poorly on marble and limestone.

Another punch type that is often used on hard stone, but not soft stone, are those with round carbide tips. These penetrate stone, especially hard stone, more easily than square tips, but the round shape tends to simply poke a hole in soft stone, rather than wedge away chips. The Trow and Holden company makes an interesting variation on the round punch that consists of a round punch on one side, and a sledghammer–like face on the other. The point is not swung at the stone, but placed on it, and the hammer head struck with a second hammer, similarly to a bull hammer or a splitting hammer, except that one person wields both hammers. The flat face can also be used as a hammer itself. This tool is usually used on hard stones such as granite.

Round-mouth punches are used for soft stone. The round mouth tapers to a narrow, slightly curved edge, which broadens the area of stone it bears against.

The following subsections describe the three major techniques for using a punches.

Obliquely to the Stone: Rapid removal of stock without bruising the stone. To reduce soft and moderately hard stones like limestone and marble quickly, in a controlled way, hold the point at an angle to the surface of the stone and drive it across the stone with repeated hammer blows. Each blow pops off chip, plowing a trench across the surface. Row after row, in parallel, lowers the entire

Figure 6.3: Steel punch, oblique stroke.

surface. See Figure 6.2.2 The same technique is used to remove high spots.

The inflexibility of the stone, combined with its low tensile strength, causes the outward pressure of the penetrating point to be relieved by blowing out a chip on side of the chisel where the stone is weakest, which is ordinarily the outer side.

Thus, the square profile of the marble punch is functional. Properly held, a flat side, not a corner, should face outward, in the direction the chip should fly. The flat side spreads the outward wedging force evenly over a large area of the surrounding mass, delaying the breaking of the the chip. This allows the outward pressure to build up enough so that when the chip pops off, the stone above the tip is thick enough to pull out a wide area of stone from around the tip.

A round punch would not work as well for this stroke because the round side of the punch concentrates the outward wedging force, instead of diffusing it, breaking the chip prematurely. The same thing happens if you hold the punch rotated by forty-five degrees, causing a corner, instead of a flat side to face outward.

The punch is held at about a forty degree angle to the work and struck solidly with a hammer or mallet—ideally, one blow, one chip. To reduce a broad area, don't pick the punch up each time, but instead just drive it along forming a furrow. Don't bother to measure forty degrees; you'll feel and hear when the angle is correct. Too steep and the punch will ring, but no chip will fly; too shallow, the point will slip, scratching the stone without biting in.

Figure 6.2.2 shows the angle of attack and a pile of chips. The white lines in the illustration show the path of the punch across the stone. Note the wide separation between them, which indicates the width of the chips that are thrown.

Perpendicularly to the Stone: Rapid removal of stock where bruising is not an issue. Figure **??** shows the use of the punch straight in. This stroke can be

used either at the edge of the block, in which case it will result in a big chip breaking away, or directly into the side of the block, in which case it causes a cone of stone to be blown out all around the point where the punch enters the block.

This is very effective on limestone or marble, but it should not be used anywhere near the intended finished surface with marble unless the surface is to remain unfinished, as it bruises the stone deeply.

Bruising: Figure **??** shows the characteristics of such bruising in a sample of the same hard white marble the demonstration piece is carved from.

The right half of the picture on the left shows the effect of the punch straight in. The triangular punch mark just above the label B was directly into the freshly split face of the stone using a moderate hammer blow—about eight inches of swing. Note the white halo around the pucture mark.

The punch was also applied in the same way just above labels A and C, and the stone subsequently chiselled away to show the depth of the bruising. Approximately 3/8 of an inch of stone was removed from the original surface at mark B, and about 1/2 of an inch at mark C, and the surface smoothed. Note that in both cases, cloudy areas of bruising are still visible.

A claw chisel with five teeth was pounded directly into the surface at the top of the block in the same relative locations, with approximately the same force. The marks are clearly visible directly above the B punch mark at the top of the block. With the force spread among five teeth, the bruising is more superficial. The same depth of cut left a barely visible trace on the left, above A, and completely removed the the bruising on the right, above C.

On the far left side of the left hand picture, an area spanning the entire block from top to bottom was bushed with a pneumatic bush hammer. The bushed stone shaved away in the middle and bottom. The middle section is shaved down about 1/8th below the bottom of the deepest craters, and the lower section about 1/4 inch. Note that the middle section still shows many bruises, while the deeper cut has almost entirely removed the hammer marks.

The right hand picture shows a cross section cut through three straight-in punch strokes, similar to the ones shown on the left hand picture. Two punched craters on the top are labeled A and B, and the one on the side is labled E. The area of stone that has been cut down is about two and a half inches square, and has been smoothed with #220 grit wet/dry paper. The stone was moistened to show the surface better. Note the white clouds below and around A and B, to a depth of about 1/4 inch below the deepest point under the punctures. These are the bruises seen from the side. There is a thinner rim of white under E.

Sub-surface cracks marked D and C can be seen radiating out from A and B in both directions. At least three parallel white flaws show up under C. There are also some very faint, white, crack–like flaws extending down into the stone below and to the right of A, going at least three times as deep as the white cloud.

Note that crack D, on the left, is open, as can be seen from its dark color, which is residue of the black sandpaper that has gotten into it. The multiple cracks marked E did not actually open the stone, as can be seen from their pure

Figure 6.4: Steel point at right angles to the stone.

Figure 6.5: Bruising beneath bush hammer (left of left picture) punch (right of left picture) and cross–section of bruising (right)

white color, but still permanently disturbed the crystal structure of the stone. If the stone were to be cut away horizontally to sufficient depth to remove the cloudy areas, these cracks would still appear as white dots.

Another interesting feature of this example is how different the marks of A and B are from E, probably because of the different directions of the impacts. The grain of the stone is plainly visible, running diagonally from lower left to upper right. Therefore, the direction of impact for A and B differs from E by 90 degrees with respect to the grain. Punch mark E removed the most stone, yet seems to have produced the shallowest cloudy area. The white region under E is also thin and parallel to the broken surface, rather than puffy cloud, and there are no obvious cracks. The lesson here is that the depth of bruising from an impact in one direction is not a reliable indicator of what you will find from another side of the stone.

Carbide v. Steel: Steel punches are not hard enough for granite; carbide is a necessity. For softer stones, carbide punches and steel punches have very different working properties and feel. A carbide tip may be just as sharp as a steel tip, but the angle of the faces coming together is greater for carbide. The wider angle means that the point doesn't penetrate the stone as deeply before the chip is blown out, causing the tip to gouge a narrow groove across the stone, rather than a wide furrow. Thus, you won't get good results in marble and limestone with a carbide point using the oblique stroke.

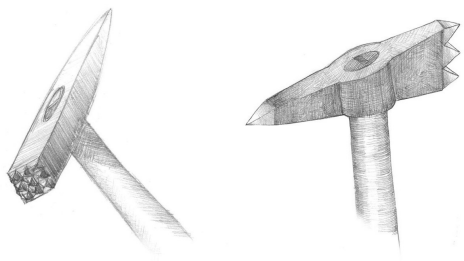

Figure 6.6: On the right, a small pick and bush hammer combination. On the left, a three-pointed hatchet, after Vasari.

6.2.3 Pick

The pick, a hammer that comes to a faceted point similar to a punch, was once a very common tool for roughing out marble and limestone, but is not often used by modern carvers. It is swung to remove a lot of stone quickly and is often illustrated among the tools of Medieval and Renaissance sculptors. It is essentially a punch and a hammer in one, and like a punch, can be used either obliquely or straight in. The popularity of picks with stone masons is regional. In some places they are still a common tool for dressing stone, probably because the local stone is easy to work with that tool. Picks with heads weighing up to several pounds are available in both steel and carbide. Figure 6.2.3, shows

a small pick with a bush hammer on one end. This is a popular small format for student use, but it is more useful as a bush hammer than as a pick because it is too light for roughing out. The pick end gets used mostly as a one-point bush hammer. Teachers sometimes recommend this tool for a student's first carving, on the grounds that the crudeness of it forces the student to keep the carving simple, and pay attention to the nature of the stone, rather than to the carving tool, but it's basically a toy. On the right is shown a three-pointed hatchet and pick combination modeled on the one in Vasari's [Vasari 07-2] book on technique. This tool is almost unknown today.

6.2.4 Tooth Chisel (Claw Chisel)

Punches and picks clear stone away quickly, but they leave a very rough surface like a plowed field. To get to the next level, a toothed chisel, or claw chisel is used. The most common types act exactly like a row of punches bound together. The claw takes away less stone, but in a much more controlled way, leaving a surface that is still rough, but is much more uniform.

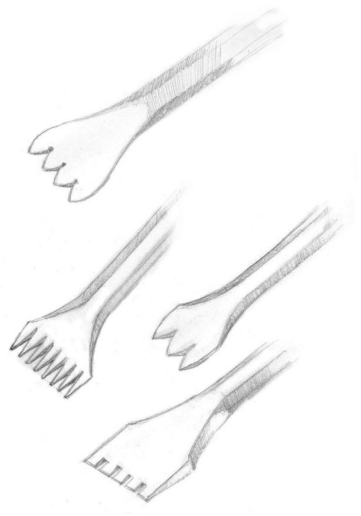

Figure 6.7: Some of the many styles of tooth chisels.

Tooth chisels, also called **claw chisels,** like punches, come in both steel and carbide-tipped versions. The carbide holds up much longer than steel but typically cost about three times as much. Carbide tooth chisels handle more similarly to their steel counterparts than do carbide punches. They require no sharpening, and last much longer, so even at three times the price they are a good deal. The drawback of carbide tooth-chisels (aside from the expense) is that the carbide tips tend shatter or detach from the steel very easily if you drive the tool head into a tight space, squeezing the teeth from the side even slightly. They have very little strength in this direction, and no power to cut into the surrounding stone, so teeth are often break or get wrenched out.

The **flat claw** chisel is a common variant. The teeth of flat claws are more like miniature flat chisels than punches. The edges are and aligned with line of cut. They take a finer cut and leave a distinctive notched pattern in the stone.

Tooth chisels are not solely for rough work. Many sculptors have used the distinctive texture they leave as a finished surface. Figure **??** shows the surfaces left by various tooth configurations.

Michelangelo relied heavily on claw chisels, and frequently left large areas of the sculpture with an extremely rough clawed surface that was often only a degree finer than that left by the punch or pick. He also used claw chisels to more delicately, to texture surfaces to control the play of light. Figure 6.8 shows Michelangelo's use of the fine claw as a finish tool.

Bernini, among the greatest masters of marble technique, sometimes used finely clawed surfaces in a way that resembles engraving, to define and emphasize the contours. Figure 6.2.4 illustrates two subtly different uses of the claw chisel by Bernini. Note the stone on which the dog's foot rests—the marks of the

Figure 6.8: Michelangelo, *Brutus*, detail, 1540, H 95 cm. Museo Nazionale del Bargello, Florence.

fine claw are the final surface of the stone. The dog's foot is similarly striated, but the final surface has been further smoothed with abrasives. Note that the striations on the dog's foot are essentially *graphical* rather than sculptural, in that they emphasize the contours of the sculpture and do not attempt to literally model the dog's fur. This piece was executed when the artist was eighteen years old.

Contrast this with the costume detail to the left 6.2.4 in which fur is directly modelled with a fine tooth chisel. While both artists control the play of light, the unknown French sculptor has worked on several levels, directly rendering the rich surface of the ermine trim, and subtly taken advantage of the whitened, crushed stone left by the claw tips to suggest the sheen and visual depths of the fur.

Note also the undisguised use of the drill in carving the gaps behind and between the braided ropes.

Hard Stone

Tooth chisels are not usually used in carving granite and other extremely hard stones, but a variety called a *ripper* sometime is.

Figure 6.9: Gian Lorenzo Bernini, *A Faun Teased by Children*, detail, 1616–1617 Metropolitan Museum of Art, New York, Marble, H. 52 in. (left) Unknown French, *Bust of a Magistrate*, detail, Metropolitan Museum of Art, New York, Marble (right). The claw as a finished tool in both pieces. In the dog's foot, both raw and polished clawed surfaces can be seen. In the collar closure, the claw is used to simulate fur. Note also the use of the drill between the cord fasteners.

Rippers are superficially like tooth chisels, but the teeth are like little flat chisels turned *vertically* with respect to the line of the cut. Figure **??** shows a ripper in action. Notice that although it is superficially similar to a claw, it works by a different principle. The geometry of the teeth precludes penetrating and wedging, but tend to act more by crushing the stone superficially.

6.2.5 Flat Chisels

When a stone worked with a tooth chisel is very close to its finished contour, the sculptor will usually switch to the flat chisel. Here, the wedging principle still applies, but the tool has an edge, not points, so it cannot get very far under the stone before the outward force crumbles the waste stone.

Edge chisels are a finishing tool—they are not usually used for removal of bulk stone. The chisel is held at a low angle, struck with the mallet. If the tool is sharp, and the angle low, it will leave a smooth matte surface. If the cut is a little deeper, it will leave a striated, rougher surface.

Droves are very wide edged chisels that typically do not have the two-sided bevel of an ordinary flat, but are bevelled on only one side. Figure 6.2.5 shows an array of chisels and roundels.

Roundels are like flat chisels, but with a slightly curved edge. The curvature makes it possible to finish depressions in the stone smoothly. Rondel gouges are also available.

Sometimes when chiseling marble, the flat chisel leaves behind craters in the stone, marring the mostly smooth surface. What's happening is that the chisel, biting into the stone, gets too strong a grip, and instead of immediately crumbling the stone just behind the edge, a larger chip is pried up in advance of the edge, and it snatches out a some stone from below the intended surface, leaving a crater. Figure 6.2.5 the upper left quadrant shows a relatively smooth chiseled surface marred in several places by pits caused by grabbing. A large pit is seen just above and to the right of the center, and several can be seen just above the lower edge of the chiselled area.

The quadrant below ws surfaced with a claw with carbide points for teeth, and the one to the left was cut with steel claw with chisel teeth. Notice that in both cases, the higher surfaces between the teeth could be described as nothing but pits, but none of them go below the plane defined by the cutting edges.

Flat chisels are available in both steel and carbide. As usual with carbide tools, the angle of the cutting edge is greater, so the tool must be held at a steeper angle, resulting in a less pleasant feel.

Hard Stone

Carbide-tipped flat chisels are also used on granite and other hard stones. As with points, the tool acts primarily by crushing the granite rather than cutting

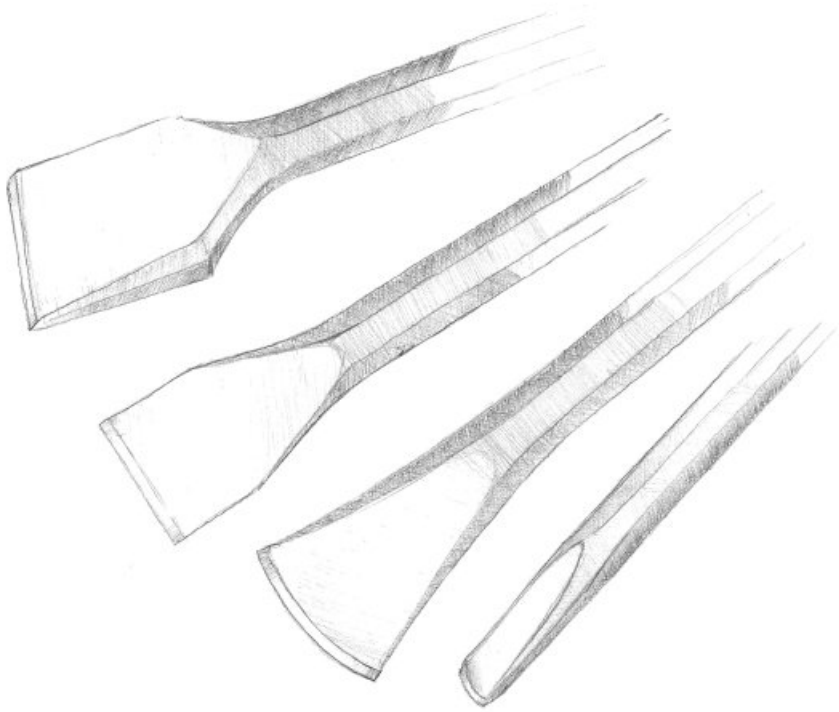

Figure 6.10: Steel chisels: flats (top) and roundels (below).

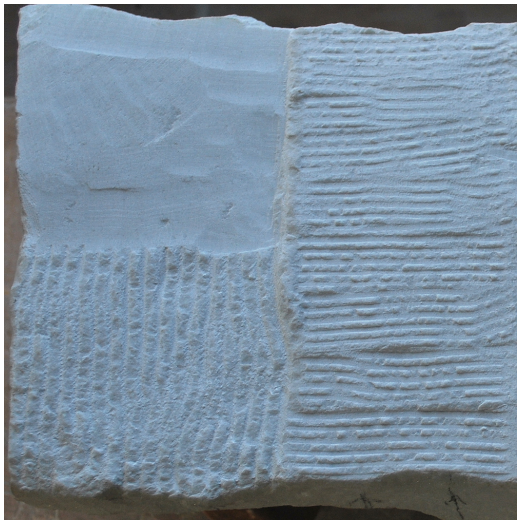

Figure 6.11: Chisel-smooth surface on the upper–right quadrant, showing pits from “grabbing” .

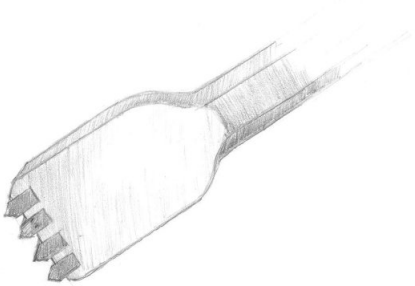

Figure 6.12: Carbide-tipped ripper chisel.

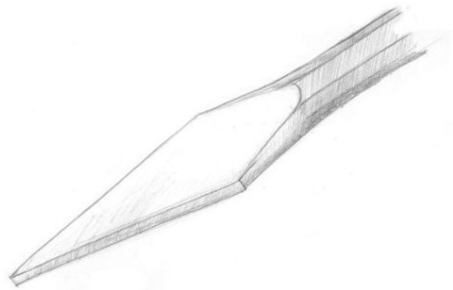

Figure 6.13: A steel cape chisel for incising lines in stone.

it. Chisels specially designed for granite should be used—the cutting edges are thicker and tool generally more rugged.

6.2.6 Cape Chisel

Cape chisels are a variation of the flat chisel. They have a diamond shaped head and a cutting edge perpendicular to the flat side of the chisel. This tool is used for incising lines in stone. Variations on this chisel have shaped cutting edges. Figure 6.2.6 shows the distinctive cutting end of a cape-chisel. This tool is also used by masons for clearing the mortar from between bricks or blocks, and thus can sometimes be obtained at an ordinary hardware store.

6.2.7 Mushrooms

The striking end of chisels are not hardened, and therefore tend to gradually mushroom as they are beaten on. Figure 6.2.7 shows a badly mushroomed tool in front, and what it should look like in back. Mushrooming makes the chisel harder to strike accurately and the rolled edge eventually breaks up, leaving sharp edges. Keep the ends close to their original shape by touching up periodically with a bench grinder. If you don't have a bench grinder you can lock the chisel in a metal vice and use a small angle grinder to clean it up. Very often flea-market tools are found in this condition. If you are buying old chisels to re–grind into sculpture tools, the mushrooming can be a clue to the quality of the steel. As a rough rule of thumb, deep cracking and broken off chunks around the edge of the rolled steel edge indicate higher carbon content. This is a good thing for stone tools. If some segments have broken off, so much the better. If the steel rolls around little cracking, it is probably a milder steel that will not harden as well when heat-treated. You can verify this by grinding on the bench grinder. Tree like branching sparks indicate high carbon. Low carbon steel tends to make sparks that form long straight lines.

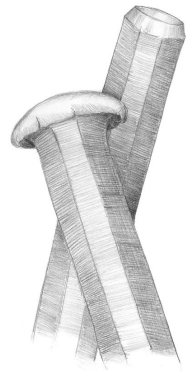

Figure 6.14: A mushroomed chisel-head (front) and the same one, properly trimmed (rear).

6.2.8 Drills

Drills have been an essential tool for sculptors since at least the Greek early Classical Period. The use of the drill tends to fall into a few categories:

- For outlining figures against a background. This is done both because it indelibly marks the silhouette, and because it honeycombs out most of the stone from otherwise difficult to carve inner corners.

- Removing stone from tight places, such as between carved folds of drapery, locks of hair, etc. preparatory to subsequent carving with a chisel. For instance, when carving the folds of drapery, sculptors of the Classical Period often drilled a long line of holes to honeycomb the stone between the folds for easier removal with other tools.

- Superficial use, in which all or part of the hole remains visible, such as in carving lace, the pupils of eyes, or carving inner curves of many kinds, such as curls in hair, etc.

- As a marking tool for indirect carving. Some form of mechanical guidance is used to drill a hole into the stone in such a way that the bottom of the hole marks a point just above the intended finished surface of the carving. The sculptor then carves down, removing the drill hole, until the bottom of the hole is reached. (The teminating dimple of the drill hole is left until the final carving, to mark the precise spot.)

When you know what to look for you will see the traces of this tool in carvings from all eras, from the Classical Period onward. The danger in using a drill is that the eye picks out the regularity very easily, both the perfect roundness and the repetition of the same size holes. Drilled holes are easier to make than to

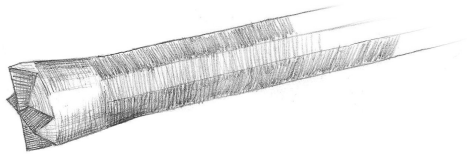

Figure 6.15: The cutting end of a stardrill or sculptor's drill.

disguise, and over-using the drill often leaves a piece looking like it's taken a load of buckshot.

Using a drill to honeycomb an area of stone is common technique. Say, for instance, you want to separate two masses of stone with a long deep cleft. A closely spaced line of drilled holes can remove the majority of the stone (use a depth-guage on the drill bit!) There are two main ways this can go wrong. First, a moving drill has a lot of mass, so if your holes are too close, it is possible for the thin wall between the current and previous holes to break, causing the drill to bind, producing enough outward force to split the stone. It doesn't take as much force as you might think.

The second way this can go wrong is after drilling, when you are removing the remaining stone. You cannot simply break out the walls between the holes with a chisel, as either the chisel, or the fragments, pushed by the chisel, can easily produce enough wedging force to split the stone. Think how little force it takes to split a huge block with feather-and-wedge.

Instead, use a grinder or a rasp to cut through the stone between the holes. When using a chisel on the remaining stone, never use it in such a way that the chisel can touch both sides of the gap at once. Structured carbide rasps are good this, but be sure your rasp does not have a taper that can wedge the stone apart.

Manually powered drills have rarely been used by sculptors since power tools became available, but historical examples are illustrated in Figure **??**.

6.2.9 Running Drill

The running drill has rarely been used since the early Twentieth Century, but it was a major tool for stone carvers since the Late Archaic Period of Greece. The name "running drill" is a misnomer. This tool fulfilled a function more like that of a modern die-grinder. It worked much like a bow-drill, but instead of making a hole, the drill bit was pushed along the surface to make a half-pipe groove. It was usually a two-person tool, with one operator holding the tool tip to the work, and applying pressure, and the other providing the power, either by bow or by pulling alternately one two ropes, which were wound around the shaft in opposite directions.

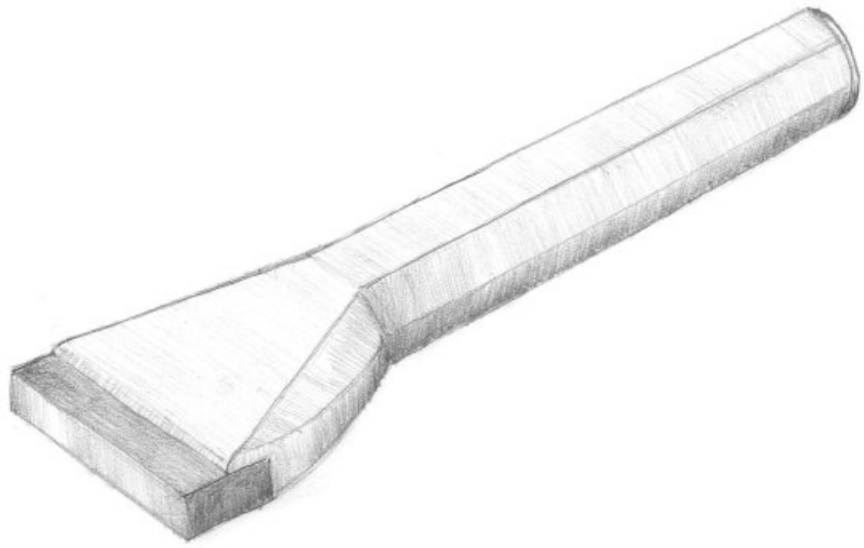

Figure 6.16: Carbide tipped pitching tool (a.k.a. hand set).

There is no reason to use this tool today, as a die-grinder or flexible shaft tool is more versatile and more effective.

6.2.10 Pitching Tool

A pitching tool looks at first glance like a wide straight chisel, but instead of having a sharp edge it has a broad square edge with a sharp 90 degree angle on each side.

Modern pitching tools usually have a carbide insert for the cutting edge, but steel works fine, if the stone isn't too hard. When using a steel pitching tool on hard stone, you may need to incise a line first with a carbide chisel or tracing tool.

This is an expensive chisel, but you can easily modify a heavy mason's chisel to serve the same purpose by regrinding the edge. A steel mason's chisel only costs about ten dollars new, or you usually can find ones at the flea market. In regrinding the edge, be sure not to burn the steel—work slowly and dunk the tool frequently in cold water. See Figure 14. for details on hardening and tempering.

Pitching tools are an exception to the wedging principle by which most of the stone carving tools work.

This tool is usually used on rectangular blocks. Place the chisel's edge

parallel to the edge of the block, at a forty-five or fifty degree angle, and tap it a couple of times first to set the edge. Then hit it hard, once, with a heavy hammer. As the sharp edge bites into the stone, it brings the flat side to bear on the stone adjacent to the cutting line. The flat edge can't enter the stone, so the momentum knocks a big chunk away in the direction of the blow. Note that this is a completely different principle from that of the punch, which either wedges away the stone perpendicularly to the direction of the hammer or in the opposite direction. Figure 6.2.10. illustrates a pitching-tool. The pitching tool can useful for removing a lot of stone quickly, but it only works on outside corners.

The handset is used by sculptors for roughing out, but is more often used by masons, who use it to give a distinctive rough hewn face to rectangular blocks used in walls. The faces of such blocks that contact other blocks are hewn or sawn square and flat, while the fronts are pitched off with this tool to give the characteristic appearance of broken stone facets. Sometimes a margin is chiseled around the edge of a pitched block to give a clean appearance. The pitching tool is alternately called a hand set. Its action is similar to that of a bull hammer.

6.2.11 Tracing Tool

A tracing tool, shown in Figure 6.2.11, is a heavier, more rugged version of the straight chisel, with a broader edge. This chisel is used to score straight lines into the flat side of a stone for subsequent splitting. The tool splits stone in two ways—first by weakening the stone along a line by starting a groove in the surface, then by wedging the stone apart. Its action is similar to that of a splitting hammer.

6.2.12 Bull Hammer and Splitting Hammer

The bull hammer and splitting hammer function more like the pitching tool and tracing tool, respectively, than what we ordinarily think of a hammer.

Bull hammers seen in Figure 6.2.12. have a working edge that is flat on the face and square, with sharp 90 degree corners, much like a pitching tool. The bull hammer requires two workers. The hammer's edge is placed on the stone, near one side and held by one worker. The back side of the hammer is struck with a heavy hammer or maul by a second worker. A single blow divides the stone. The break line can be incised first with a tracing tool. It is important that the edge sits against a flat surface. A curved surface can break the edge.

Splitting hammers shown in Figure 6.2.12. are used used in the middle of a stone, and work like tracing tool. Like the bull hammer, one worker holds the tool in place, and the other hits it with a heavy hammer. Both of the bull hammer and the splitting hammer are of more interest to masons than to carvers, but they can be used effectively to rough out blocks, make stone bases, etc. As with a bull hammer, the full cut line may be incised first with a tracing tool or chisel. As with the bull hammer, it is important that the tool be used on a flat surface, and not on a bump, as the uneven forces could break the edge.

Figure 6.17: Carbide-tipped tracing tool.

6.2.13 Bush Hammer

A typical bush hammer, shown in Figure 6.2.13, looks like a meat-tenderizer, the face being cut into a waffle pattern of little pyramids. With the momentum of the hammer behind it, each pyramid can apply tremendous pressure to a tiny point to crush a crater into a struck surface. Repeated striking reduces the surface to a continuous field of craters which are cratered again and again, gradually removing material to any depth, or simply unifying the surface texture. Bush hammers aren't used as often on marble as they are on harder stones, but they are sometimes used for texturing.

It is not necessary to hit hard—a rap is enough. Bush hammers are available with a many different face designs, with fixed or replaceable faces, and in both carbide and steel. Carbide has made steel bush hammers more or less obsolete except for use on soft stone. Chisel-like tools with bushing heads are also available for places that aren't accessible to a hammer.

Bush hammers are useful even on softer stones like marble and serpentine because of the textured, matte surface they produce. Bushing faces for marble often have more numerous smaller teeth. Obviously, bushing should not be used on marble if the surface is to be further smoothed because of the deep bruising. Bushing tools for soft stone are sometimes called frosting tools.

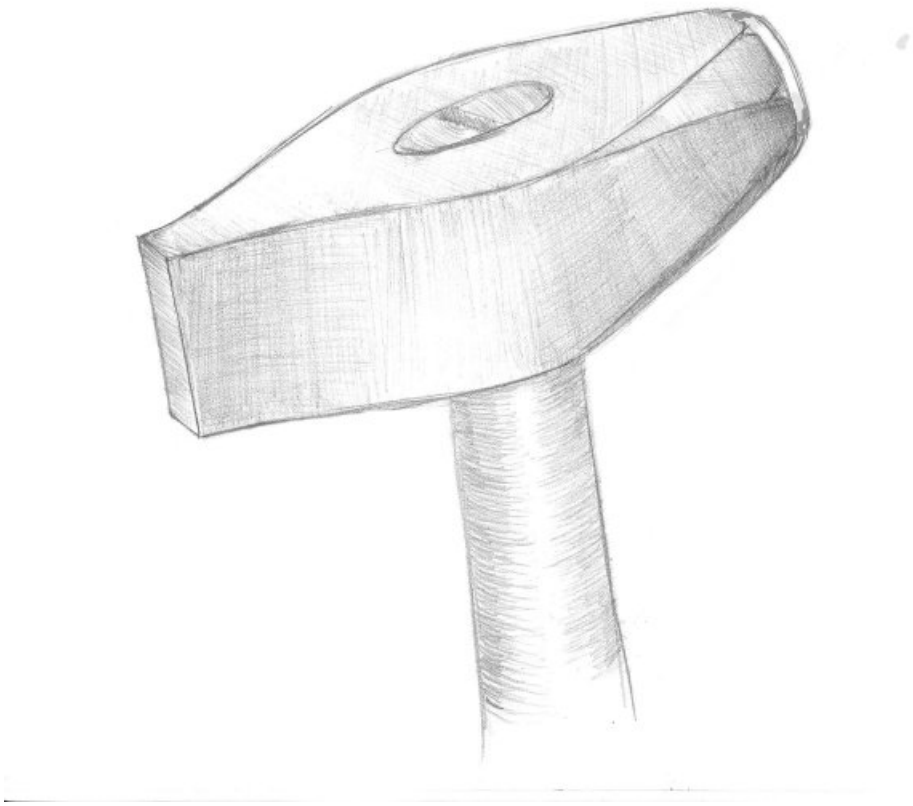

Figure 6.18: Bull-hammer (a.k.a. bull set).

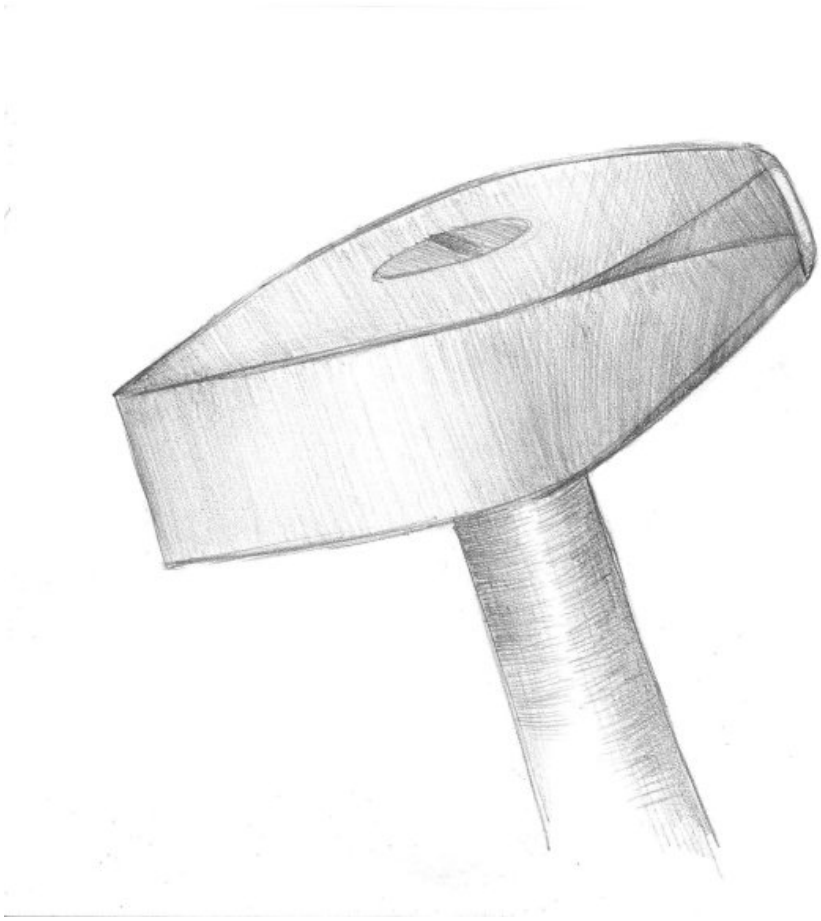

Figure 6.19: Splitting hammer.

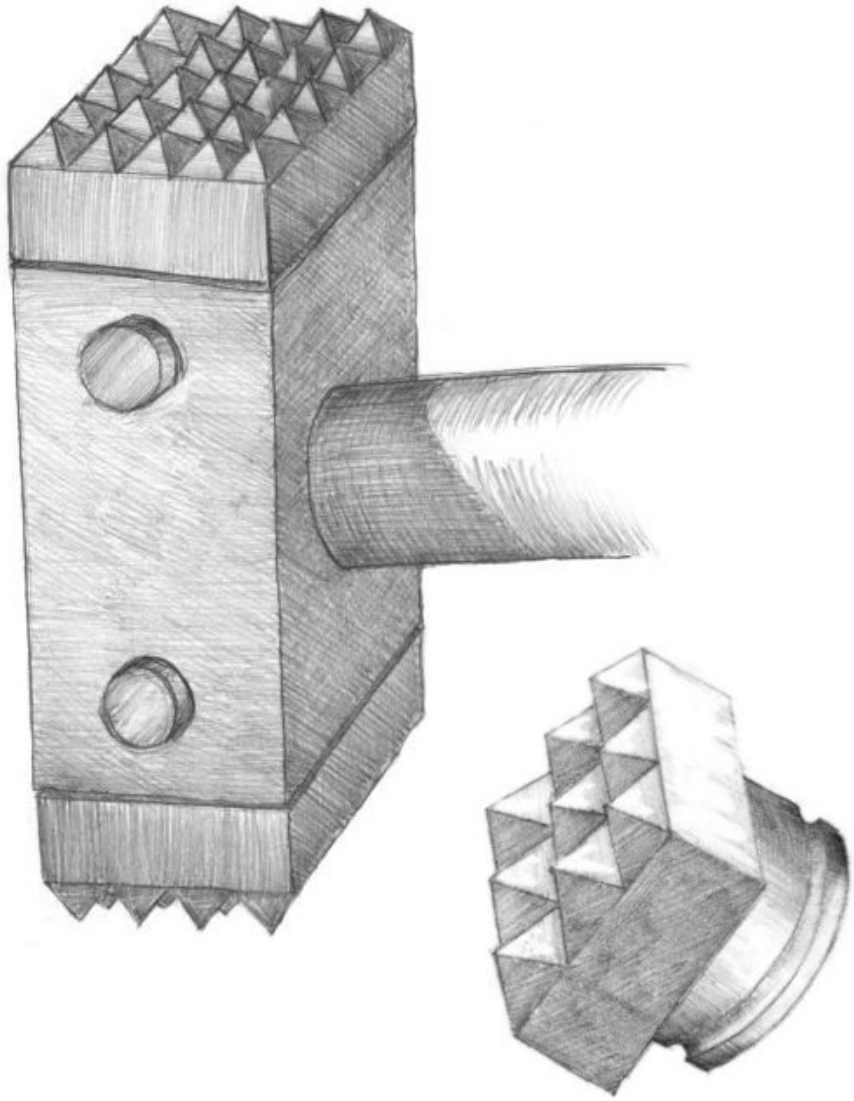

Figure 6.20: A bush hammer with replaceable faces.

6.2.14 Hard Stone

Granite and similar stones are too hard for normal chiseling, and are usually carved by sawing, bushing, and abrasion. Sawing is often used to remove large amounts of stone, and then followed by bushing to do the intermediate shaping. Grinding with silicon carbide or diamond abrasives follows, unless the bushed surface is to be left as is. Four points is the most common configuration for stock removal on hard stone, but Bush hammers are also available with crosses, circles and other shape on the striking face, in lieu of waffling. Entire sculptures can be carved with nothing but the bush hammer.

Bush hammers for granite usually have fewer, larger, points than hammers for marble and other softer stones.

6.2.15 Rasps, Rifflers and Files

Rasps come in all shapes and sizes but the principle is constant; a rasp is a piece of steel with the surface worked into an array of cutting teeth. Rasps are made from a soft tool blank by driving a hard tool into the surface at an oblique angle to tear up little tongues of metal that will serve as cutting edges. After the teeth are formed the tool is heat-treated to harden it. Unlike chisels, the edge is not usually tempered. Rifflers are small, shaped rasps. They are available many shapes, sizes, and degrees of coarseness.

There's a hazy line between rasps and files. In general, files usually have a series of parallel edges machine-cut into the surface, as opposed to the teeth being clawed up from the surface of the steel. But there are exceptions of nomenclature in both directions. A variety of rasps and files are illustrated in Figure 6.2.15.

To use a rasp, simply lay the cutting surface against the work-piece and push forward with simultaneous downward pressure. Avoid pressure on the return stroke to prolong its useful life. Rasps are most used on soft and moderately hard stones such as marble.

One traditional rasp, shown in Figure 6.2.15,is called a stone mason's drag. It is made by setting sections of hacksaw saw blades into a block of wood. The block is pushed perpendicularly to the direction of the blades to rake stone from the surface. They are mainly used to flatten surfaces. The Shinto Corp. makes a modern version, shown in Figure 6.2.15, that is intended for woodworkers, but works on softer stones.

6.2.16 Modeling The Surface Without a Hammer

The most common way to model a soft surface is with chisels and roundels, followed by rasps, and finally sanding. Surfaces that do not have tight outward curves can often be modeled more easily and precisely by pushing and edged tool by hand. Carving without mallet or rasp is particularly good for subtle surface modulations of flesh, strands of hair, drapery, etc.

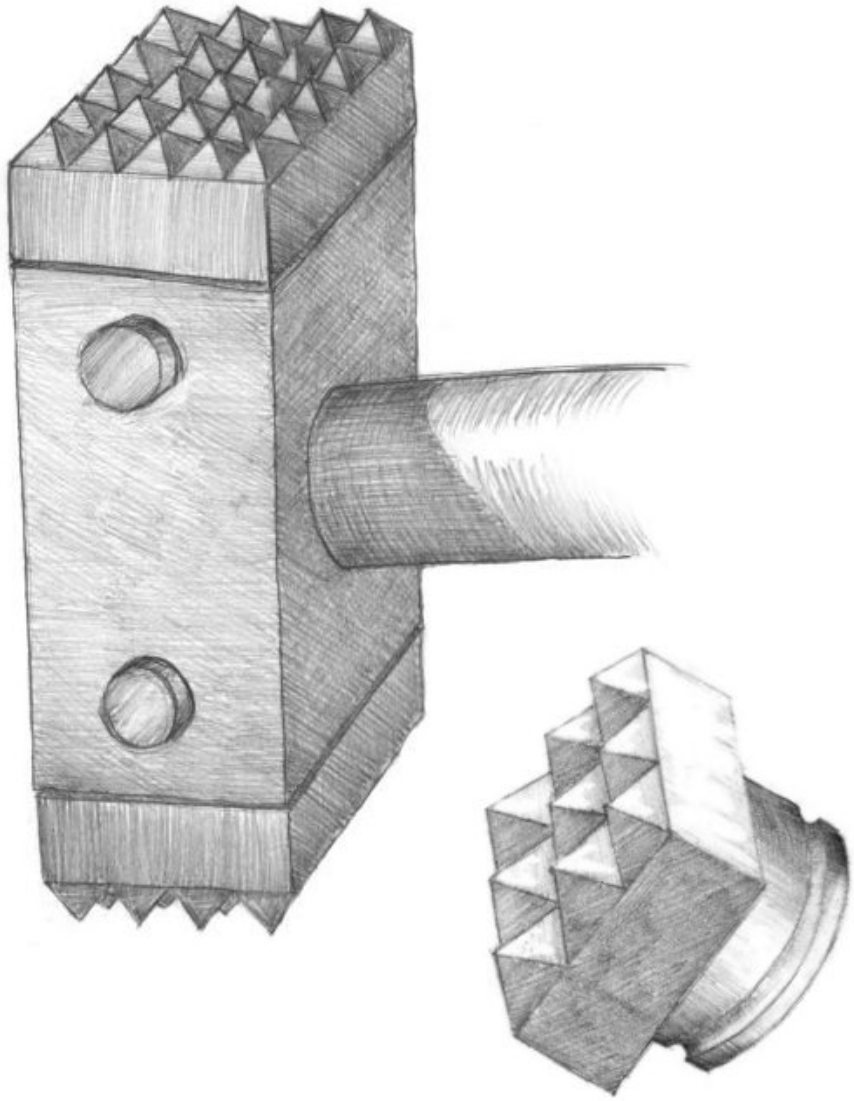

Figure 6.21: A selection of rasps and rifflers.

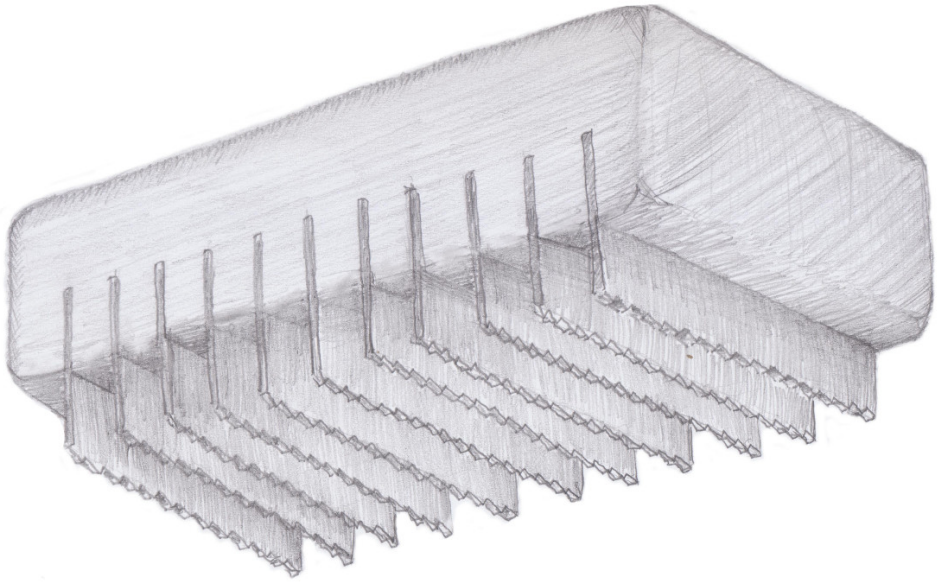

Figure 6.22: A mason's drag.

Figure 6.23: A saw rasp made by Shinto Corp., Japan.

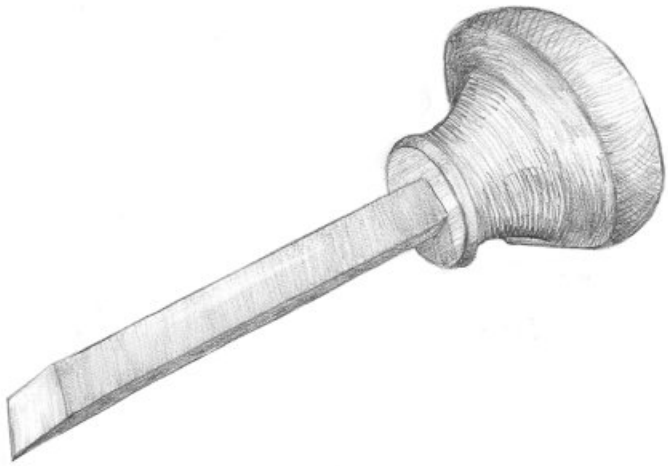

Figure 6.24: An engraver's burin with the standard edge.

Incisions

Incisions such as might be used for rendering hair, clothing seams and similar purposes can often be cut with an engraving burin, shown in Figure 6.2.16. Where an edge rolls softly away from an incision, for instance where skin is deeply wrinkled, use the burin to cut the sharp part of the crease, followed by the inside curve of a woodworker's gouge, to cut the roundness of the skin at the edge of the creases in the skin at the base of the fingers in the marble piece in Figure 6.25 were done this way. The cutting edge of a gouge used in this way needs to be completely reground so that the bevel faces the outward, rather than inward. The overall bevel should still be the sharp, 30 degree angle of a wood chisel, but the acutual cutting edge of the bevel should be steep, say, 70 degrees. Only about 1/16 or less should have this steep bevel, so that he sharp corner can fit deep inside the incised groove. The inward curve of the couge will help to shave off stone in such a way that minimal or no sanding will be required. You don't necessarily have to incise the groove first to use a chisel like this. With a little practice you can use the corner of the gouge directly, skipping the first step.

Figure 6.25: A softly modeled surface carved with push-chisels.

You will have to regrind your tools continually as you work. Even soft stones frequently contain traces of silica other minerals that quickly dull a blade. Don't use good gouges for this—you'll grind them away to nothing, and good ones don't hold up with stone any better than the cheap ones. A good way to carve hair, cloth, and similar complex surfaces is to chisel the overall shape, then do the detail carving without a mallet as described above.

Sharp tools used in this way will leave an finish similar to that of #220-grit sandpaper—fine enough that for many purposes the tooled areas will require no further polishing.

Surfaces

Subtle modulation of flesh, cloth, leather, and similar gently curved surfaces can be accomplished with carpenter's wood chisels reground in this way. The cutting end should first be ground to a curve. You can grind a partial bevel back along the curve if the thickness of the steel will interfere with your view, but it is not necessary.

The cutting edge will be sharp—as describe above—but the edge will be almost a right angle as shown in Figure **??**. Buy the cheap, no-name carpenter's chisels that come five sizes in a plastic pack, for five or ten dollars, so you can have a range of curvatures to choose from. By varying the angle of incidence to the stone and the relative angle of the chisel and the direction of push, a continuum of curvatures can be obtained from a single chisel. the skin showng veins and tendons in in Figure **??** was modeled this way.

The edges on these chisels must be fresh to work well, so they should be touched up frequently on the bench grinder. They don't need to be honed, just ground with a fine grit wheel. The tools leave smooth surface, about what you get with 120-grit sandpaper, and takes off stone about as fast as a fresh rasp, but leaving a silky smooth surface.

Steel for woodworking is tempered to be quite soft, so unless they are heat–treated, these tools dull within minutes. However, heat treating is trivial in this special case because, as they will not be subject to the stress of hammering, they do not need to be tempered. After the intital grinding to reshape the edge, heat the tips to cherry red using a MAPP gas or propane torch, and keep them at that temperature for a few minutes. Be sure it stays cherry red, but not hotter. You can wrap the shaft near the handle with a sopping wet cloth to keep avoid damaging the joint to the handle. While it is still cherry red, plunge it directly into cold water and keep it there until the entire tool is cool enough to touch. (If just the tip is cooled, heat can migrate down the shaft and temper the tip.) When it is cool, give it a final wet grinding, and them wipe the tool with oil, as it will otherwise rust very quickly. After this treatment you can go much longer between sharpenings.

Chapter 7

Power Tools

Some extremely useful additions have been made to the marble sculptor's tool kit in modern times.

7.0.17 The Pneumatic Hammer

Probably the most useful new addition is the pneumatic hammer, invented by Willam Holden, of Barre Vermont, in 1888. A modern version of this hammer is seen in Figure 7.0.17.

This tool is just a smooth-walled socket to hold the chisel, with a piston at the back that strikes the chisel hundreds of times a minute. The chisel does not lock in—if you let go, the hammer will bounce it out. They are noisy, vibrate, and raise clouds of dust, but the stone just spews from the tip. They're fantastic. Both of the hammers shown are equipped with a valve so the air can be turned on and off during use.

Claws and straight chisels work very well in a pneumatic hammer. Punches can a disappointment even on soft stone if your hammer is underpowered, because they require some weight behind them when you are doing bulk removal of stock. The ideal size for working with the claw on marble or limestone may be too small for working with the punch.

The relative performance boost provided by pneumatic power is probably the greatest for bushing, particularly for hard stone—bushing a substantial mass of stone without a pneumatic hammer is a waste of time. A wide assortment of bushing heads are also available.

Sculptor's pneumatic hammers are small—anywhere from the size of a Mont Blanc fountain pen, up to the size of a can of spray paint. The larger of the two shown here is a general purpose hammer, and is about an inch and a quarter in diameter and eight inches long. It's actually a bit small to drive the punch shown, even with the pressure turned up high, but is more than adequate for all the other tools.

The choice depends on how big you're working and on the type of stone. They are all very expensive compared to commercial pneumatic tools, but the

Figure 7.1: Two sizes of air hammers and some of the many tools they can drive.

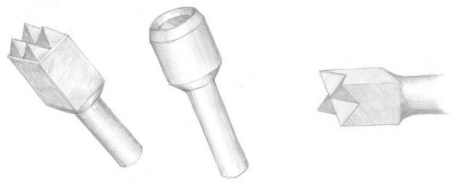

Figure 7.2: Bushing heads for pneumatic hammer: bush and cup (left), star (right), granite tip.

big ones aren't much more expensive than small ones.

Other than the overall size, the big variable is stroke length. For a given cylinder size, the longer the stroke, the harder it hits, and the slower the cycle time. Hammers designed for granite have a longer stroke, which means they consume more air, and the larger hammers consume a lot—up to 8 CFPM, which is greater than a three to five horsepower contractor grade compressor can provide. But that's a very powerful handle. Most marble carvers will be more than happy with a model that consumes a maximum of 4 CFPM. More about this below.

Both steel and carbide tipped chisels are available. Steel tools:

- Useless for hard stone.
- Cheaper to buy, but many have much shorter working life, and all require much more maintenance.
- More acute edge angle means better penetration for some tools, and more stone removed for a given amount of impact.
- Better working feel for delicate carving.

Carbide tipped tools:

- Work for both hard and soft stone.
- Last many times longer if used correctly, and require much less maintenance.
- Some tools can be more fragile if used carelessly, e.g., claws.
- Can be used with higher power settings.

For softer stones, many carvers find that for tools with edges, steel tends to work somewhat better than carbide, but this has to be traded off against the frequent maintenance required. Carbide seems to have the edge for claws.

Carbide tooth chisels last a long time without sharpening, but they tend to lose or break their outer teeth very easily if they are used in any situation that results in pressure from the side. Running the chisel into a tight space,

approaching an inside corner from an angle, or even grazing against a slight knob of stone when chiseling across a surface can cause this. Steel is much more resilient, and less likely to break in this situation, but wears down more quickly and eventually breaks from fatigue.

Only when the corner is clear can you safely run a tooth chisel parallel to the corner. To clean out inside corners, go into the corner first on low power with a sharp punch to get the solid rock out, or come in perpendicularly from one direction then the other with the tooth chisel.

The down side of pneumatic hammers is the noise, vibration and dust. In addition to the safety glasses and mask, you need ear protectors. Padded gloves are a good idea for extended use, because any vibrating tool can cause a variety of problems, explained in detail in Chapter 15.

7.0.18 Compressors

Pneumatic tools are rated for both *air pressure* (pounds-per-square-inch, or, PSI) and *volume,* expressed in cubic-feet-per-minute (CFPM). The CFPM consumed by a tool varies with air pressure, so both a low and a high number are usually given in the product specification. The numbers given for hand tools are the minimum pressure it requires, and the maximum pressure it is designed for, and the amounts of air it will use at those pressures.

Almost all compressors, regardeless of size, produce at least 120 PSI, which is more than enough for almost any air tool. The two places where compressors differ significantly is in the CFPM rate, and in the size of the air tank. Think of it like a truck—they all have more or less the same top speed (PSI) but a semi can haul more (CFPM) than a pickup truck.

The compressor motor has only has one setting—flat out. If the tank pressure falls below a set amount, say 120 PSI, the motor will automatically turn on and run until the tank pressure reaches some slightly higher limit, say, 135 PSI, and then cut off automatically. Should the cutoff mechanism fail for any reason, the pressure that can build up in the tank is limited by a spring–loaded valve which can only hold back slightly more pressure than nominal maximum for the machine, say, 140 PSI. Above this maximum, the air pressure in the tank will lift the valve and bleed off the excess. These valve usually also have a finger ring that can be pulled to manually empty the tank at any time.

If you are taking air out of the tank a rate lower than the CFPM rate of the compressor, the tank pressure should always stay in the range established by the automatic on/off levels, which is more pressure than you usually want. Therefore, every compressor comes with a device called a regulator, which maintains the output air pressure to the air hose at any set pressure, regardless of fluctuating pressure in the tank. Most compressors out of the box have two pressure meters, on for the tank pressure, and one for the regulator, which shows the line pressure. You simply turn the regulator knob until the line pressure is where you want it, and it will maintian that pressure for you automatically. If you turn the regulator knob down, it will automatically bleed air from the line until it reaches the desired setting.

Figure 7.3: A typical five-horsepower shop compressor capable of running air tools.

The CFPM rating of a compressor varies with the line pressure. The compressor pictured here puts out 6.6 CFPM at 40 PSI, and 5.8 at 90 CFPM, which easily covers the typical operating range of the pneumatic hammers shown above, but would not be enough to run an angle grinder or other heavy duty tool. In the long run, the CFPM for your compresser must be greater than the combined CFPM's of all the tools that are running, but a big air tank will let your total air usage spike to a much higher rate for a limited amount of time. The more intermittent the tool usage, the more a big tank extends the number of tools that can be supported. This can greatly extend the number of users in, say, a gas station, where multiple mechanics use high–CFPM tools like wrenches, but only for a few seconds at a time. Carvers, however, tend to use tools like chisel handles and grinders, that stay on continuously, the CFPM rate of the compresser, must be more closely aligned with the tool ratings. In practice, it is best to have a wide margin of extra CFPM capacity above what you intend to use, so that the machine does not have to run continuously to keep up. Even a big tank doesn't provide more than a few minutes of heavier use—the tank pictured holds 26 gallons, which is only 3.35 CF. The hammers shown here are rated at 3.0 and 4.0 CFPM, so you could run two of the small ones more or less continuously, but two of the big ones would overdraw the maximum output of the compressor by two CFPM. It is easy to see that draining a 3.35 CF tank at 2.0 CFPM doesn't provided much of a buffer even at a low pressure setting.

Most of the contractor and home grade electric powered compressors you will find at a big–box store for $200 to $300 produce less than 3.5 CFPM, which is just barely enough for the small pneumatic chisel, but not enough for the big one.

At 3.5 to 6.0 CFPM, pneumatic chisel handles are on the low end of air consumption for pneumatic tools. Pneumatic grinders, sanders that can run wet, die grinders, drills, etc., are all available, and are often cheaper and more powerful than their electric counterparts. Pneumatic die grinders are very appealing because they are powerful, won't burn them out, are safe around water, and are cheap—you can get a decent one for under $60. However, even the smallest of them use about as much air as a chisel handle, and air consumption can go far higher for bigger ones. Angle grinders are hogs, requiring as much as 40 CFPM. Unfortunately, this level of air usage adds a decimal place to the price range for an adequate compressor, and the total energy cost goes up too, because air tools consume far more power electric tools for equivalent performance levels.

7.0.19 Maintenance

Compressors need regular oil changes, and you should check the oil level periodically. Consult the manual to find out what grade of oil yours requires. In most machines, the plug for the oil intake hole has a built in dipstick. Dirty oil, low oil, or the wrong kind of oil will shorten the life of the compressor.

All compressors have an air filter that should be cleaned frquently. If you don't clean it, it quickly chokes up with dust and the machine has to work too hard to suck in air. Take the filter out, blow it clean from front and back with

compressed air, and put it back daily, or more often, depending on how fast it gets dirty. No filter is perfect—it's best to locate the compressor away from dust sources to minimize the dust and grit it is exposed to. Ideally, put the compressor in a closet with an outside vent, as you would a water heater. This will keep the noise level down as well.

The compressor tank collects condensed moisture as the compressor runs. At the end of the day, the compressor should be turned off, and the water drained by opening the cock at the bottom of the tank, allowing the remaining air in the tank blow the water out. Leave the cock open until the tank is empty, then tighten it again.

Water also condenses when it leaves the pressure regulator. Most compressors have a built in water catcher after the regulator, but before the air hose connecton. These devices have a bell shaped jar beneath them where the water collects. There is a cock at the bottom to let you drain it periodically.

7.0.20 Tool Operation

Most air tools require frequent oiling. Two drops of 3–In–One oil into the air intake every hour or two is ok for hammers and many other air tools. A better way is to install a line oiler near the point of use. These devices spray a little oil into the compressed air just before it enters the tool. Don't use this device on air lines you intend to use to spray paint!

One extremely nice studio accessory is fixed pipe on the wall to supply compressed air to several outlets, each with its own regulator, so the pressure can be regulated independently for different tools. This lets you connect the tools with thin, ligh, plastic air hoses, rather than the usaul heavy rubber hoses.

A second big benefit of this is that water can condense in a long air hose. A fixed pipe lets you put a second water catcher close to where the air will be used eliminating most of the water that would otherwise collect and end up spraying out your tool's exhaust port. The main pipe should be installed with a down-slope and a valve at the lowest point, so you can drain the water periodically.

7.0.21 Rotary Grinders

Almost as handy as a pneumatic hammer are the many variations of rotary grinders. These tools are phenomenaly versatile, and come in many formats and sizes, and can be powered by either electricity or air. They range in size from heavy, two handed die grinders that can drive a heavy grinding wheel, or a ten-inch diamond saw blade, down to a Dremel tool the size of a tube of toothpaste, driving a bit with a diamond grinding wheel the size of a match head.

The physical hazards are much like those of pneumatic hammers: noise, dust and vibration, plus the added danger of severe cuts, abrasions, and electrocution. But again, it's easy to protect against these hazards if you use some sense: never work sitting down, keep your hair tied back, your shirt tucked in, and your

Figure 7.4: Electric die grinder (left), pneumatic die grinder (right).

sleeves squared away, and wear ear plugs, glasses, and a respirator. And wear padded gloves if there is significant vibration for long periods.

The *aesthetic* hazards of grinders are harder to protect yourself from. Of all the tools available to the stone sculptor, grinders pack the biggest danger to the artwork. They work a too well, doing what they do so effectively and effortlessly, that it's easy to get led around by the tool. Grinders are one of the leading causes of insipid sculpture.

Die Grinders

These tools are characterized by small, one-handed size, and may be either pneumatic of have either a built-in electric motor. They work at very high speed (up to 30,000 rpm), and therefore are intended for use with bits and wheels of small diameter, usually under 1.5 inches. Within that limitation, they can be used with a huge variety of stones, steel or tungsten carbide cutters, diamond and fiber saws, drills, cut-off wheels, polishers, and other accessories.

They can have the shaft rotaion inline with the tool, or at a right angle, and may may either have a cylindrical shape or a pistol grip. The collet size is usually 1/4 or 6mm, but may occasionally be smaller or larger. They work very well for general purposes but tend to be somewhat clumsy because the motor is part of the tool. On the left *in Figure* 7.0.21 is an electric 1/4 inch die grinder, and on the right, a similar air powered tool. Both tools are priced at about sixty dollars. Air-powered grinders tend to be smaller, but they last a long time if they are oiled periodically when in use. Electric tools are much cheaper to run, but the brushes may need to be replaced occasionally.

Dremel, though a proprietary name, has become almost a generic term for small die grinders. Other companies make similar tools but Dremel dominates the market. They are light duty, but extremely versatile and flexible, and are manufactured in a in a range of grades.

These tools have a 1/8" collet, and a huge variety of bits are available for sawing, sanding, grinding, drilling, etc. For stone carving, they are only useful for small details. Buy a good one; they burn out fast under heavy use. A typical

Figure 7.5: One of many Dremel tools, with accessories.

Dremel tool and accessories can be seen *in Figure* 7.0.21. This kit sells for about sixty dollars. Buy the kind with a power cord, not the rechargeable models, which are not adequate for heavy use.

Flexible shaft tools are a heavy duty alternative to die grinders and Dremel tools. They have 1/4 to 1/2 horsepower stationary motors, providing as more power than an ordinary die grinders, with but with a smaller hand piece, because the tools are driven by a flexible shaft connecting the hand piece to the motor. The motors may be either mounted on the floor or hung from the ceiling, and are usually controlled by a foot pedal. Hanging configurations are more convenient.

Flexible shaft tools handle a wide range of bits that are interchangeable with other die grinders, and can usually accommodate a many collet sizes from 1/16" to 3/8". The prices for these tools vary wildly, from $50 to $750 or more. Two flexible shaft tools and accessories are shown.

in Figure 7.0.21.

Figure 7.6: Two popular flexible shaft tools and accessories.

Angle Grinders

These heavy-duty tools are useful for shaping, smoothing and polishing big simple sculpted shapes as well as blocks for bases. They can also be used to drive cut-off wheels for almost any hard material. Be aware that different wheels are required for steel and stone.

Angle grinders may be powered by either electricity or air. Air powered grinders consume large amounts of compressed air, but unlike most electric tools, can be used with water. There are also electric grinders that are designed to be used wet. Whether electric or pneumatic, grinders that are specifically designed to run wet will almost always have a hose coupling and valve to supply a stream of water to the center of the cutting tool.

Beware that wet grinding requires wheels specifically designed to run with water.

For granite and other hard stones, a heavy duty angle grinder is almost an essential, both for carving and for finishing. Shown *in Figure* 7.0.21. are some typical large angle grinders that can be used for sawing, grinding, and polishing hard or soft stone, or for grinding and cutting metals. Smaller versions that use 4 1/4" wheels are also common.

An angle grinder can be used to remove large amounts of stone quickly by cutting a series of deep, parallel cuts into the block using a diamond wheel. Use a hammer or a hammer and chisel to knock out the resulting leaves. If the cuts are not on a corner, it is important to free the leaves on their ends with

Figure 7.7: Some typical seven to nine inch angle grinders.

perpendicular cuts, in order to avoid wedging the stone apart when you break the leaves off.

Some angle grinders can be equpped with a dust shroud that can be hooked to a shop vac.

Battery powered angle grinders also exist, but are not suitable for the extended use that is typical in the studio. They are also relatively expensive.

Angle grinders drive a wide variety of cutting, grinding and polishing tools suitable for working with stone. Among these are:

- **Solid Tungsten Carbide Burrs:** These are rotary files and rasps cut from solid tungsten carbide. They are extremely hard and capable of shaping soft and hard stone very quickly.

- **Diamond Burrs:** Come is a range of sizes and shapes similar to those available for carbide burrs, but have an abrasive surface composed of diamond particles. They shape any kind of stone and are extremely durable, but cut more slowly than carbide.

- **Abrasive Stones:** Also come in range of shapes and sizes similar to the those available for carbide burrs, but are solid, rock-like concretions of silicon carbide, aluminum oxide or other abrasive. They are slower cutting and change shape as they wear. Beware the differences in hardness—silicon carbide, also known as carborundum is necessary for granite-like stones. Silicon carbide, and aluminum oxide will both work on marble and softer stones.

- **Cut-Off Wheels:** These function like circular saws, but usually cut by abrasion. They may be metal, with diamond or carbide grit bonded to the edge, or fiber impregnated with resin and abrasive particles. They are capable of cutting into any kind of stone. Diamond wheels are most effective on hard stones. The metal wheels remain the same size throughout

their useful life. Fiber-resin wheels wear down quickly until they will no longer reach the work-piece.

- **Flexible Abrasive Disks** These are made of heavy plasticized cardboard coated on one side with abrasive. They run mounted over on a rubber backing disk, may be used to work the surface of very soft stones. In general are not very good for stone work.

- **Cup wheels:** These rigid metal cups have the abrasive on the rim and are useful for smoothing and flattening the sides of stone blocks and slabs. They are also used for smoothing compoundly curved surfaces. The cup configuration is available in most grinding media.

- **Kutzall wheels:** This is a brand-name for a line of structured carbide cutting heads available in many shapes and sizes. They have a very rough texture composed of carbide bonded with softer metal, and are great at ripping through large quantities of stone (or almost anything else.) They come in numerous shapes and degrees of coarseness for both angle grinders and die grinders.

The color of a grinding stone is significant. White, pink, and grey signify aluminum oxide, while green and black indicate silicon carbide. Aluminum oxide stones are suitable for soft stones, but will not cut harder stones like granite. The surface of some aluminum oxide stones may tend to pack with waste, reducing the capability of the stone to cut. Silicon carbide stones, also called "carborundum" will cut practically anything hard except diamonds.

Operating an Angle Grinder

The blades and motors of rotary tools, particularly the larger tools, can carry a lot of momentum. Should an abrasive or metal wheel bind in a cut, the tool can kick back hard. The operator should be in a comfortable, centered stance, feet well planted, knees slightly bent. Arms should be tight to the sides, in such a position that some of the force of a kickback will be transmitted through the back of your upper arm to the side of the chest—you don't want to rely on the strength of your arms alone for safety. Long hair must always be tied back, and your shirt tucked in tightly. Sleeves should be buttoned or rolled up securely. A shirt brushing against a blade can wind instantly around the wheel, yanking the tool toward the operator's body.

Another common accident is plugging in a grinder when the switch lock has been inadvertently left on, causing it to skitter across the table or floor. Trigger locks automatically release when you pull the trigger, so be in the habit of squeezing the trigger once before plugging in any power tool.

For obvious reasons, never operate an angle grinder sitting down, and never operate one in an uncomfortable or awkward position.

Wheels and bits can disintegrate because they are damaged or defective, or because they are rotating at a speed beyond their designed limit. A broken

Figure 7.8: A typical rotary polisher (left) and an electric wet polisher (right).

wheel can throw pieces very hard, so keep your face out of the plane of rotation. It's a good idea, to let a wheel run a briefly in a safe position before putting it to the stone.

In the age of product liability, everything comes with a warning label; do not confuse this one with the kind of warnings that come on tack-hammers or boxes of toothpicks; these accidents happen often!

Polishers

Polishers look like angle grinders, but are lighter duty. These are good for flat surfaces, or large curved surfaces, but they are not of much use for figurative sculpture.

Some polishers accept a water hose input, and are capable of running water into the center of the cutting head for lubrication and cooling of the cut. Usually, water-equipped polishers and grinders are pneumatic, but electric versions also exist which have water resistant bodies and ground-fault protection built in. Needless to say, wet work must not be attempted with an electric grinder that is not specifically designed to be used wet. Check the CFPM requirements of your compressor before spending money on a pneumatic polisher—they are hogs for air. Some typical polishers can be seen *in Figure* 7.0.21. Neither is an expensive tool–under $150 for the wet polisher, and under $100 for the dry polisher.

Bench Grinder

A bench grinder is is an essential tool in the studio. The most common are electric powered, with two wheels, one on each end of the shaft, as pictured *in Figure* 7.0.21. A wire brush wheel on one side, and a silicon carbide stone on the other is a good combination. The wire brush is good for removing rust and

corrosion from metal, and the silicon carbide will grind both steel and carbide tools.

The trouble with powered wheels is that they spin fast, and heat tools very quickly, so it's easy to burn steel cutting edges. Keep a pot of water on the bench, as shown, so you can wet the steel frequently. As the steel gets thinner it heats faster and can burn is a split second—as you get closer to a fine edge, use a lighter touch, and only for a second or less, before backing off to let the steel cool.

A good way to practice is on old junk tools. As you grind, look for any discoloration near the tip as you work. The instant you see it, the hardness will have been removed. This will help develop a sense for how fast the metal heats. If you are making tools, this is not an issue, as you will be hardening and tempering them again anyway.

The final grinding should be done either by hand, with a coarse oil stone, or with a water wheel, as shown. The base of the water wheel is filled with water, and it is cranked by hand (the crank is on the far side in the picture.) Even though they are slow moving, wet wheels cut fast, because you can grind continuously, and it is almost impossible to burn a tool on a wet wheel. Powered wet wheels are the best, but they are very expensive and don't add much for stone tools, which do not demand the kind of precision grinding that one would want for woodworking tools. Water should not be left standing in the tools when they are not in use, as it can sometimes soften the stone on the side that remains wet, causing it to go out of true sooner than it otherwise might.

Almost all grinders come with an adjustable tool rest. It is not always necessary, and sometimes it is convenient to work without it. It has been temporarily removed from the powered grinder, but the wet wheel is shown with it mounted. More expensive grinders often have a quick-release catch for the tool rest, so it can be removed and replaced easily. This is a feature worth paying a little more for.

Always inspect wheels carefully when remounting on a powered grinder. Verify that the rotational speed is consistent with your motor speed, and check visually for any damage. Do a tap test as well. A cracked wheel will usually have a distinctive dead sound, like a cracked bowl or cup. If you discover that a wheel is cracked, break it with a hammer to prevent reuse. The pieces can be useful on both steel and stone.

After being used for a while, wheels can cake up with residue of metals (especially if you grind non-ferrous metals) and they can develop grooves, rounded corners, etc. All of this can be fixed with a dressing tool, which come in two varieties. Diamond dressing tools cut a new surface. They can consist of a single diamond on a long handle, or an edge with several diamonds mounted on it. They are rested on the tool rest, and the diamond(s) held to the wheel and moved from side to side to shave a layer from the surface. If the wheel is out of round, a fixture can be used to hold the tool steady enough to cut it back to where it is a perfect circle with the hole exactly in the center. This cannot be done without a fixture of some kind.

The other kind of dressing tool consists of a heavy handle with a cylindrical

Figure 7.9: A powered bench grinder with wire wheel and silicon carbide stone (left) and a hand–cranked aluminum oxide wet-wheel.

stack of star shaped wheels on the working end. The handle is held to the tool rest, and the wheels pressed to the spinning stone. Because of the gaps, they impact the stone hundreds of times a second, acting like a precision bush hammer against the point where the cylinder touches the wheel. The wheels on this kind of dressing tool wear down, but they are replaceable.

7.0.22 Drills

The picture *in Figure* 7.0.22 shows a range of standard drills for the studio. The first is a one-handed 3/8-inch cordlless drill is handy in the studio for drilling holes in wood and driving small screws. The use of these drills is limited by their light motors, but even more by their keyless chucks. The chuck is the part that holds the bit. Keyless chucks consist of two rings, which turn in opposite directions, and tighen three jaws around the drill bit to clamp it in place. A keyless chuck is quick and easy to use, but limited in how tightly it can hold the bit, and therfore, how much torque it can apply when drilling with conventional bits. This can be obviated by using bits with hex shafts.

The second drill is a 3/8" corded version, also with a keyless chuck.

The third and fourth are 1/2 drills. These are necessary for heavy work,

Figure 7.10: Drills: 1/4" cordless, 3/8" standard, 1/2 with switch for hammering, heavy duty 1/2" with D handle.

such as driving large screws, drilling holes in stone, boring holes in timbers, mixing plaster and cement, and similar tasks require a lot of torque. They can look somewhat like a 3/8" drill, or they can have a D handle in the rear and straight handle sticking out the side. The two different formats are pictured.

If a 1/4" or 3/8" drill binds in a hole, you hand will usually easily stop the drill, but 1/2" drills are much more powerful, and are stronger than your wrist at full power. Therefore, even the pistol grip types usually have a detachable handle on the side for applications where a lot of torque is applied.

Good 1/2" drills often have a switch that lets them function as hammer drills. This is a feature worth paying for. The red drill in the picture has this feature. With the hammer feature, these drills have enough power for the majority of stone drilling in the studio, and quickly switch back and forth, which can be very convenient when drilling marble. A drill is often used in conjunction with carving, but with marble, you must not hammer drill close to the finished surface, because the impact can leave deep permanent bruises in the stone. With a switchable drill, you can drill most of the hole with hammering turned on, then switch it off for the last inch or two.

Conventional drills with a switch that lets them also hammer, while they are quite powerful, are the least powerful class of drills for this purpose. True hammer drills are the next step up. Thse drills are intended primarily for masonry. They still have a conventional chuck with three jaws, like regular drill, but are intended primarily for masonry work. Some of them rotate as much as four times faster than ordinary drills in hammer mode, and they are considerably more capable on stone, but are not really indended to be used as drills for wood and metal.

At the top of the heap are true rotary hammers, which are very different from conventional drills or hammer drills. The most obvious differences center around the chuck. The masonry bits used by an ordinary drills and hammer drills have a plain cylindrical shaft which is gripped tightly by the chuck. In contrast, the rotary hammer takes an SDS–style shaft, which fits loosely in the drill, and is slotted, so that it can slide back and forth, but cannot fly free. This allows the hammer mechanism to impact only the drill, without having to also move the chuck and shaft. A rotary hammer and some typical SDS bits are

Figure 7.11: Typical rotary hammers.

pictured *in Figure* 7.0.22.

Most rotary hammers can be set to drill-only or drill-and-hammer. Some can also be set to hammer only, without rotation, which is a nice feature. A range of bits such as punches, chisels, and spade—like chisels are available that let the rotary hammer double as a demolition hammer. These tools are too clumsy to be useful as general purpose carving tools, but their large size gives them a lot of impact, and they can be useful for special purposes.

Non-rotary Drills

Old fashioned star drills that you tap with a hammer have power–driven cousins that are intended to be used with a pneumatic chisel handle. The drill tip shown *in Figure* 7.0.22. consists of a plain shaft with a chisel–like carbide blade across the tip. Like a manual star drill, it is twirled with the fingers as it is danced against the stone, and gradually pulverises a round hole into the stone. These drills are not usually used for utility work such as drilling holes for splitting, but are often used more often for holes that are part of the carving. They are convenient because they are driven by the same pneumatic handle that the sculptor is using for the rest of the work.

Figure 7.12: Percussion drill manufactured by Trow and Holden.

Chapter 8

Abrasives

8.1 Finishing Marble

There were major improvements in the technology of abrasives in the Twentieth Century, which have significantly affected how marble sculpture is finished. The finishing process that is most often seen today, particularly on abstract sculptures, results from a process that resembles the finishing of commercial marble or wood. This process produces a flawless finish that may or may not be suitable for figure sculpture. Both processes and some variants are described below.

For both finishes, smoothing usually starts with either rasping or grinding with some other coarse agent, either of which leaves visible scratching. These scratches are smoothed away using a sequence of finer and finer abrasives.

The standard commercial process, which is used by the majority of modern sculptors follows:

- Each abrasive grit is used until the entire surface is uniformally finished to that grit level, i.e., no scratches coarser than the current grit level are visible.

- Then the next finer grit is applied until all scratches from the previous grit are removed, and the procedure reiterated with finer grits until the desired degree of polish is reached.

- The finer grits are usually applied with water, which lubricates and washes the waste away.

- If a truly glassy finish is desired, the final abrasive is a paste rouge, or a paste of tin dioxide.

- Either a petroleum based marble sealer or oxalic acid marble sealer is applied as the final stage. (More on oxalic acid below.)

- Some sculptors follow this with wax. This is not a good practice—the oxalic acid will leave it plenty shiny without polluting the surface with organic chemicals that may later discolor.

The finishes used on marble before the Modernist era was often more complex, particularly in the late Nineteenth Century. Many earlier sculptors did not step through this rigid polishing process, and the differences were essential to the vividly lifelike appearance of the work of many sculptors, particularly in the late Nineteenth Century. The importance of the traditional smoothing process is often missed by modern sculptors. Although the abrasives we use have changed tremendously from those used a century ago, but the same effect can be obtained with modern abrasives. The older smoothing process was roughly as follows, but there were many variations. Modern abrasives are not exactly analogous step for step, but approximations are given in modern terms.

- The surfaces were rasped or ground to a fairly coarse grit that leaves visible scratches—equivalent to perhaps a 60 grit, 40 grit, or even coarser level.
- After the coarse smoothing, a fine grit was used that to finish the surface without fully obliterating the network of scratches. In modern terms, this would be like jumping directly from 40 or 60, directly to #150 or #220 grit paper. Under magnification, you see that perhaps 95network of scratches remain, much like the minute cracks you see if you look at your skin under high magnification.
- Tin dioxide was often applied as a polish.
- The final step was rubbing with oxalic acid. The oxalic acid not only sealed the polished flat surface, but also the whiteness at the bottom of the fine scratches.

The result is a much richer surface, that imitates some of the more complex visual properties of skin. In particular:

- The scratches have a significant depth, and their rough unpolished inner surfaces throw off light in all directions, resulting in sub-surface light scattering that more accurately resembles that of live skin.
- Much as with real skin, the resulting surface varies in reflectivity, being a network of tiny, slightly lustrous patches separated but minute cracks. The scratches separate the relatively shiny areas not just by their minute internal shadows, but by the luminescence they produce around them below the surface.

Note how different both approaches are from the practice of the classical sculptors. We now know, as the Renaissance sculptors did not, that Classical sculpture and temple architecture was painted or othewise polychromed. To the ancient masters, marble sculpture of the Renaissance and later periods would

look as unfinished as would a bare plaster wall. Thus, they did not attempt to achieve either the flawless surfaces of contemporary carving, or the visually richer surfaces typical of sculpture before the 20th C. Many ancient sculptures have either been so weathered or so roughly cleaned over the centuries that it is difficult to tell what their original unpainted surfaces were like, but there appears to have been very little attempt to achieve the lustrous appearance of more modern works. Instead, early Classical and Archaic period works are usually chalky looking, more like limestone in appearance, at least partially because of the degree to which they were bruise in carving.

8.1.1 Traditional Marble Finishing Sequence

The traditional materials for final smoothing and polishing are mostly obsolete. Actual chunks of stone were used, and the final polishing was usually with various powdered abrasives. Modern materials are much better for most stages of smoothing. The traditional polishing sequence used in the late 19th and early 20th C. is given by Malvina Hoffman. Note that many of these are not longer commercially available, having been replaced by modern abrasives.

- Fine emery stones: these are sold for sharpening tools.
- Coarse sandstones: not commercially available anymore.
- Fine sandstone: not commercially available anymore.
- Pumice stone: This is a foamy volcanic glass that can be composed of many kinds of minerals. The walls of the tiny air cells are rigid mineral, and the broken edges proved a continuously renewed abrasive as the surface wears away. It is no longer sold as an industrial abrasive in rock form, but can be had in powdered form at the hardware store. The rock form is often sold for cosmetic use for smoothing off calluses.
- English hone: a fine mineral powder.
- Putty powder: a putty composed primarily of chiefly stannic oxide. Also called also jewelers' putty. Stannic oxide is also known as tin dioxide. Older preparations often contained lead.
- Powdered oxalic acid: used as a paste or as a solution in water, this chemically seals the marble and makes it more lustrous. This chemical is still available in the hardware store. It is used to remove iron stains from stone, enamel fixtures and masonry, e.g., rust stains from water that has been in iron pipes. While oxalic acid occurs naturally in small amounts in some foods, it must be used with care, as it is both irritating and toxic in the more concentrated form used by artists.

8.1.2 Oxalic Acid and Other Chemical Sealers

Used either as a water-paste or as a dilute wash, oxalic acid was used as described above on marble sculpture, and as the final finish on commercially cut marble slabs. This chemical soaks into the stone and links the crystals together, forming a dense relatively waterproof layer. Note that the modification to the structure of the stone usually changes the light–transmitting properties of the stone, making it more transparent and reflective. Oxalic acid is sometimes applied mixed with tin dioxide, in either paste form or as a dilute solution, to combine a final polish with the sealing. It can also be applied after the tin dioxide (or other final abrasive) as a thin solution. Using using oxalic acide for the final step is a form of patina, analogous to a bronze patina, in that it permanently chemically modifies the stone.

There are also other chemical finishes that pentrate marble with mineral solutions, that work in a similar way, inter–linking with the calcium carbonate crystals to form a dense shell. These chemicals are used in commercial sealers for high wear surfaces, and tend to leave a hard finish that can be mirror shiny.

8.2 Modern Sandpaper

Sandpaper is a 19th C. invention, although it was previously invented in China in the 13th C. Many kinds of abrasives, papers and other backings, glues, etc., have been used, an the technology is still evolving. The most important attributes of a sandpaper are

- The type of abrasive, which determines what substances it can cut.
- Whether it is open or closed coat, i.e., whether there is space between the grains, or they are jammed tightly together on the paper. Closed coat papers have more cutting edges per square inch, but tend to pack with waste material, and work best wet. Open coat papers let the waste fall away more easily, but have more space and fewer edges per square inch, so they cut more slowly.
- The backing, and whether the abrasive is intended to be used dry or wet.
  - Dry papers are usually for coarser sanding on softer stones. These kind of papers made for woodworkers work well on marble, but usually wont work for hard stones. The abrasive is often either garnet or aluminum oxide.
  - Wet–and–dry papers are mostly for finer sanding and polishing. These are usually charcoal gray and as the name implies, can be used either with or without water. To use wet, just dip frequently in water. They can be used dry, but rarely are, because they pack with waste quickly. They are usually silicon carbide, and so will cut almost anything.

  - Cloth backing (emery cloth) is usually used with silicon–carbide or emery for machining applications. They are not very good for softer stones, but may be useful on hard stone.
  - Numerous other backing materials are available. Sponges impregnated with grit can be used to polish larger surfaces if detail is not an issue. Sanding belts and sanding wheels can be cut up to get relatively stiff pieces that can be used flat or rolled into stiff tubes that can be used like rifflers.

- Grit Number: grits numbered 60, 80, 100, 120, 150 on dry–type papers are most useful for softer stone. On marble, grit below 100 tends to give visible scratching, above 100 leaves a more or less matte finish similar to typing paper, that hides a lot of sub-surface detail. Grits numbered 220, 240, 320, 360, 400, 500, 600, 800, 1000 usually come on wet–and–dry papers. On marble, 220 grit paper gives a silky surface that is almost transparent, and starts to show sub–surface detail. Higher numbers give more and more polish up to an almost glassy finish with 100. Beyond 1000 grit, paste rouge is used to get a fully lusterous surface.

Numberous abrasives have been and are used for sandpaper:

- Sea-sand and crushed shells were used in some of the earliest papers. These are no longer used.

- Crushed flint, a very hard metamorphic form of quartz, was once common, but is now rare.

- Garnet is a natural abrasive that is still common. It can mean any of a diverse group of silicate minerals, and is a distinctive reddish or orange crystal. It is somewhat less common in sandpapers than formerly, having been largely replaced by aluminum oxide. It is good for sanding marble to a moderate fineness.

- Aluminium oxide is the most common sandpaper for woodworkers, having mostly displaced garnet. It is abrasive used in the pale orange sandpaper with the kraft-paper like backing. It is an excellent all–around paper for coarser sanding on marble, and other softer stones, but is too soft for the hard stones. Use this paper to get a matte, white, non-transparent finish.

- Emery cloth is mostly used by machinists, but is hard enough to abrade hard stones.

- Silicon carbide papers are available in all grits, but are most familiar as wet-and-dry papers. These are excellent for finer sanding and polishing of marble, and also work on hard stones.

- Exotics: there are numerous other abrasives for special purposes. Most will work if you happen to have them, but they are expensive and don't add anything that cheaper papers don't have for ordinary applications.

Alumina-zirconia (an aluminium oxide - zirconium oxide alloy) is used mostly for metals. Chromium oxide used in extremely fine micron grit (micrometre level) papers. Ceramic aluminum oxide used in high pressure applications for both coated abrasives, as well as in bonded abrasives (e.g. wheels). Cubic boron nitride is a substitue for diamond.

8.3 Rotary Stones and Wheels

This is a placeholder for a section of rotary wheels and stones, fiber disks, and exotic abrasives.

8.4 Finishing Hard Stones

This is a placeholder for a section on how to polish granite and similar stones.

Chapter 9

From Start to Finish

This section follows the progress of a simple in-the-round marble carving from start to finish. The block is one of the two salvaged from the badly split block shown earlier.

9.1 Planning

Carvings are usually planned in advance. The great sculptors of past ages worked from small clay or wax models, and many went further, executing each piece full size in clay as well. Ordinary wet clay is fragile wet or dry, and falls apart even when carefully handled. Plasticine is much better because it doesn't dry out, and so remains easy to repair or modify indefinitely. It's a dead looking material, but you can spray paint it.

Wax is less frequently used now than in the past, but it's a better choice in every way. It's less fragile than plaster or Plasticine, extremely permanent, and easy to modify or repair. If you opt for wax, a sculptor's wax such as brown microcrystalline wax is good. This kind of wax is beautiful without any finishing, looking very much like bronze. Microcrystalline wax is a petroleum derivative made from the refinery byproducts. Beeswax-based waxes are also good, smell better, and are environmentally benign. Recipes for beeswax-based sculptor's waxes with various properties may be found in Methods and Materials of Sculpture **??** pages 159–161[1]. Another advantage to wax is that if you like the maquette for it's own sake, it's easy to make a cire perdu mold directly from it, or if you prefer to have it cast by a foundry, you can simply send them the maquette. Wax is also reusable indefinitely, even if it picks up dirt, which you can remove easily by melting it and filtering the liquid wax through cheese cloth.

[1] Beware that some of the recipes call for lead and mercury. These metals are bad news—toxic, absorbed by ingestion or through the skin, extremely unfriendly to the environment, and highly regulated in the workplace and as toxic waste, for very good reasons. Fortunately, they aren't essential.

Your model should be complete, especially anywhere that one mass overlies another. As you work on the model, moving masses around and adding back clay, you realize how hard getting it right the first time, in stone, would have been. Some artists then whittle a second version out of a block of hard Plasticene, wax, or other material, in order to solidify their understanding of the form.

9.2 Roughing-Out

In the roughing-out phase, you can knock off corners of the stone with a heavy chisel or handset, but after that, the bulk of the stone is removed with the punch. If you are using the punch straight in, driving the punch with a manual hammer is very effective. For the oblique stroke, the choice of manual v pneumatic is a matter of taste and working style. The pneumatic hammer is vastly faster than a manual hammer when using claw chisels, edged chisels, or the bush hammer, but the speed difference is less dramatic with the punch, unless your pneumatic driver is large, with a long stroke.

The choice may come down to the degree to which you are carving directly. In direct carving, blocking out is a critical part of the creative process. Therefore, manual punching, with its slower pace, and reduced need for protective gear, makes it easier to view the masses as they develop, and allows the artist more opportunity to refine his or her vision of the piece. An artist working from an exact model has different priorities. When working in this way, with more of the decisions are made up front, in clay, the artist is more likely to see blocking out as simply a chore to be gotten out of the way. With mechanical copying, there is no issue—faster is better, period.

9.2.1 Flattening the Bottom

Figure 9.2.1 shows stone to be carved with the bottom side up. This irregular piece is an off-cut salvaged from a tile-factory, and none of the sides are flat. A punch is used to incise a straight line near the edge, with the bottom of the groove on the desired plane of face. A section of hacksaw blade from a Sawzall, or even carpenter's crosscut saw (not one you intend to use again on wood) can be used to clean up the chiseled lines. Check it for straightness with a steel straightedge.

A similar line is cut on the other side of the block. The lines do not need to be parallel, but they must be on the same plane, i.e., not skewed with respect to each other. If two straight lines intersect, then by the laws of geometry they define a unique plane. The punch is pointing at one line, and the other is the white line edge opposite and to the right. If your lines do not intersect, check for skew by laying straightedges in both grooves and sighting along the tops. If the lines are not skewed, you should be able to find an angle at which the two straight edges line up perfectly. Check visually that the plane defined by the two lines passes through stone at every point you care about.

Figure 9.1: The original stone with rounded bottom (left), cutting out between two lines on the same plane (right)

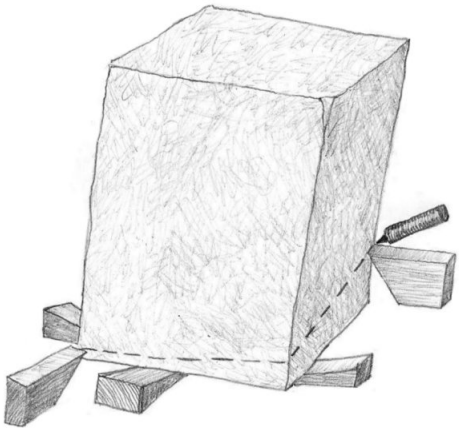

Figure 9.2: Marking the bottom plane of a block leveled with wedges.

If the base covers a large area, it can be helpful to cut some extra straight lines across the area to be leveled, intersecting with the two reference lines. In this way, the surface can be chopped into small fields, each of which is bounded by lines precisely on the correct plane. Use the punch to rough out the stone in the plane between the two lines as closely as possible and extend the plane, to cover the entire side. Figure 9.2.1 shows the use of the punch to flatten the area between the lines. When the base is as close to flat as you can make it with the point, switch to a coarse claw to even it out. Minor high spots can be identified with a piece of plywood covered in colored chalk. The board will rock on any high points, leaving them chalked. Cut them down the marked areas and repeat until the surface is flat. An useful hand tool for the final flattening is the "saw rasp" manufactured by the Shinto Industrial Company. Seen in Figure 6.2.15, this is a modern version of the traditional mason's drag. The face of the tool is an expanded grid of hacksaw blades arranged so that all their edges form a plane.

A faster but dustier way to do the final flattening is with a cup wheel on an angle grinder. Unlike other grinding head shapes, the cutting edge of a cup wheel will automatically seek a flat surface if it is kept moving.

The method described above is an general way to make a flat surface. If the block has flat sides, there's an easier way. The plane of a flat surface can marked on the outside of the block by placing the block, bottom down, on the work surface and using wedges to get the desired plane parallel to the bench top. Figure 9.2 illustrates how to use a block of wood to scribe a constant distance from the work surface all the way around the block. The desired plane can then be defined cleanly by cutting along the line on all sides with a rotary saw. For many blocks, the saw will only reach part way to the middle of the

Figure 9.3: Beginning roughing-out with pitching tool.

block, but it doesn't matter; the resulting leaves of stone can be broken off with a hammer and punch, and the flat sawn surfaces extended by hand as described above. For even greater precision, you can tack a six inch wide board to two equal height spacers, and use it to support a circular saw, with which you can cut perfect lines to the same depth across the remaining unleveled area in the middle.

9.2.2 Knocking Off Big Pieces

Use either the pitching tool or tracing tool to knock off large chunks from the corners. To use the pitching tool, hold it at an angle to the stone, rap it once or twice with the hammer to set the sharp edge in the stone, then hit it with a solid blow using a heavy hammer.

The tracing tool or other wide heavy chisel does a similar job. Score the entire intended cut line with several light blows. Then, hold the trimmer in the resulting groove and hit it solidly. The illustration shows the kind of chunks you can easily take off with either technique. The break shown was done with a tracing tool, seen in the background, which was ground from an old brick chisel. A commercially made version of either of these tools, with a carbide edge, is an expensive item.

9.2.3 Using the Punch

With the bottom flattened and the big corners removed, the real carving starts. Using the model as a guide, start removing the bulk of the stone with the punch. You can still come in from the edges with the punch, but take small bites—tangerine–slice size at most. Whether coming in from the edge or from a surface, punches will tend to break if you use them deeply enough into the stone that they stick like a stake in the ground. They are intended to be used at a depth where you usually get a chip for each time you strike it. We will be

Figure 9.4: Roughing out with the point.

using the oblique stroke only because this is marble, and bruises easily.

A one and a half or two pound hammer is plenty heavy. Feel for the best combination of angle and force for your stone. With marble or limestone, the chips should fly.

You should be removing chips ranging from the size of a quarter to size of a matchbook. If you find that you are often hitting the chisel repeatedly before getting a chip you are probably going in too steeply.

Inside Out

Even in the rawest roughing-out, deciding what to remove gets tricky. Modeling in clay is a much more intuitive process, because with clay, the work occurs in the order of the importance of the masses: first you get the big masses in the right places, then you fiddle with them, refining the overall design before you ever think about superficial features. Painting is similar—the artists lays down the chiaroscuro, then sketches-in the important shapes, quickly getting all the elements the right relative size, and in the right places, after which their size and relationship remains more or less the same. In either case, only relatively

late in the process does the artist need to consider the details because they can be added and taken away at will. In both media, the artist works from the simplest and most essential, to most detailed and superficial.

Carving completely reverses this, because stone can only be removed. Even in the crudest blocking-in stage, the sculptor must be always be acutely conscious of the finished surface, because nothing can be put back. In the conception of the work, and in the model, it is the masses are important, but in the execution, the surface is everything. Even at the crudest stage of rouging out, the sculptor must never cut below the level of even the the most superficial details, and thus, must be have an accurate picture of the finished piece from the first stroke of the punch. The more complex the composition, the more precisely the sculptor must understand the masses before the carving starts, because there is nothing in the stone that is analogous to the cartoon that the painter draws on he canvas, and then paints on top of. Because the finished piece must be imagined so accurately at the outset, refinement of the overall desgin does not really occur in the carving stage, except in the simplest, monolithic pieces.

Ironically, though sculpture is ostensibly about mass, the actual process of carving stone deals first and foremost with surfaces, and while painting is ostensibly about a two-dimensional surface, the painting is built up from the inside out. Only when sculpting the simplest monolithic forms does the sculptor work like the painter, continually refining a basic shape into something more precise. This is the essence of why Michelangelo, arguably the greatest painter, and certainly the greatest sculptor of his time, categorized modeling in clay as a branch of painting, and considered sculpture limited to carving.

If there are multiple masses, getting them in the right relationship is unintuitive. The roughed-in masses are much larger than the forms they enclose will be when finished. As each mass is carved smaller and smaller, their positions in space relative will change relative to the other masses, or instance, If two masses just touch in the rough, they will be separated by a significant distance when fully carved.

Undercuts irrevocably commit the masses involved to a particular relationship, so always put them off for as long as possible. Instead, as far as possible, come straight in from the outermost surface of the raw stone toward the imaginary center of the carving. When the roughing-out is done, the center of each mass must be the same absolute distance from where it will finish, not the same relative distance.

The coarse punch work in the example was done using both hand and pneumatic hammering. Air is not really necessary at the pointing stage, but it can speed things up, especially as the work gets finer. As the rough carving proceeds further, a pneumatically driven punch will be used more.

9.2.4 Coarse Tooth Chisel

The punch leaves the surface so rough that it is hard to tell what the true shape of the piece is. A coarse claw chisel leaves a more even surface, in which you can begin to see the forms. You'll want to go back and forth between the two tools;

Figure 9.5: Roughed out with the coarse claw.

as the shape of the piece is better and better defined, one can remove stone with more confidence. To bring the piece to the state pictured below should take less than a day. In the coarse clawing stage, continue to refrain from making undercuts anywhere that masses will touch or come close together,for example, where the hands rest on the skull, until the surface of the major mass is fully defined. An undercut committs the masses that it separates to a certain range of relationships. Nevertheless, the big undercuts can be opened up carefully with the drill. Hammer-drill only when there is plenty of surrounding stone, and never hammer drill within several inches of the bottom, as the drill can blow out a large chunk on exiting.

A drill can be used to honeycomb out the stone in deep cuts, but there is a danger of splitting the piece when you remove the webbing, and danger of the bit breaking the webbing between two holes as you drill, jamming, and wrenching the pieces apart.

After using a drill to honeycomb stone to be removed, before using a chisel to clear the webbing between holes, first cut the webbing with a saw or grinder. A die grinder, air powered grinder, or a flexible shaft tool, with a coarse carbide burr is good for this. A Kutzall brand structured carbide bit, shown in Figure

Figure 9.6: Carving under way with coarse and fine claw.

7.0.21 is perfiect. For fine work, a rasp with teeth on the edge is good. Even a thin web has a lot of compressive strength. if you do use the chisel, use a cape chisel, seen in Figure 6.15, with the wedge perpendicular to the holes, so that it will not wedge the stone apart.

It is much better to saw or grind through the webbing of stone that is left between the holes. A die grinder or flexible shaft tool with a coarse carbide burr is good for this. On fine work, a rasp with teeth on the edge is good.

9.2.5 Fine Tooth Chisel

In the picture below, the piece is being worked over with a finer claw chisel. The base of the thumb on the right hand has an area that is about to be chiseled, with the fine claw, indicating about how much is taken off on a pass. The dome of the skull has been flat chiseled to nearly its final surface, allowing the first undercuts to be made defining the contact point with the fingers and thumbs. Carbide burrs cut through marble quickly, and leave a fairly smooth cut, but you have to be careful in a tight spot, lest the tool bind, which can damage both the bit and the piece. A burr with a round head was used to dig out

the eye sockets after drilling two one-half inch holes to almost full depth for guidance. The tooth chisel was used to finish carving the spaces opened up with the grinder.

Eye sockets are tricky—they are not at all round in the back as one would imagine, but instead form cones that run deep into the skull.

The fine toothed-chisel has made the forms clear enough to show some serious problems. From the angle shown, one is particularly visible. Something seems very wrong with the base of the right thumb—it's way too long. The knuckle at the base of the thumb is too close to the wrist, the three sections are all too long, and somehow depressed towards the palm. Fortunately, there's still enough stone left to correct these defects, as can be seen in the next picture, below.

A crayon of magic marker is very useful. Any area to be cut down can be marked using a simple notation. I use a solid line to indicates the boundary of the cut, with perpendicular lines mark the direction to cut, and parallel lines serve as a contour map, the closer the spacing, the steeper the cut.

9.3 The Final Carved Surface

The piece is fully roughed out when the claw has been used to get most of the piece to within an eighth of an inch or so of the final surface. The last eighth of an inch is where the real action is—about half the work remains to be done at this point.

An eighth of an inch all around is still a lot of stone—it's the difference between your little finger and a hotdog. To this standard, two masses in the rough can end up as much as a quarter of an inch out of place when finished.

In this step we move from finer tooth chisels to the flat chisel for the main areas. Working over the entire surface with the flat chisel shows the final shape very clearly—at this point its possible to start doing the critical undercuts beneath the fingers confidently, so long as the lower surface is very close to its final dimensions first.

9.3.1 Undercuts

Chiseling the undercuts is dangerous. The chisel is a wedge, and tapping it into an enclosing space, even lightly, can break of the piece you are undercutting. A tiny tap in a tight space can knock off a large chunk of stone. Even a rasp, if it twists or jams can do this.

The safest way to do the undercuts is to use a grinder with a conical carbide or diamond tip having the shaft at the point, with the the bottom of the cone smooth, to cut away the bulk of the stone. Use a rasp to go deeper.

9.3.2 Flat Chisels and Roundels

The chisels, roundels, droves, etc., are best thought of as the final step between claw chisel and finishing. They clarify the surface left by the fine claw, but they are a little crude for truly finishing the stone. For carving that will be finely finished, they are best used when the amount of stone to take off is under an eighth of an inch. Any more, and a fine claw is better. For the last sixteenth of an inch or so, rasps or push chisels are better.

The critical thing with flat chisels and roundels is not too try to take too much at one pass, lest the chisel "grab" at the stone and snatch craters into it, obliging you to take that much more stone from a wide area. A sixteenth inch at a time is the most you should be taking at this point in the carving.

As with tooth chisels, the pneumatic hammer is a tremendous time saver at this point, for shaving the piece down to its final shape. Keep the chisels sharp and the power low, and be extremely wary of cutting into undercut areas or gaps. Roundels can be useful for hollows.

You can develop your own set of roundels by grinding the flat chisels to suit as needed. Do not try to turn a straight chisel into one with a curved edge by wearing away at the existing bevels. It's a bad method for two reasons: firstly, it's hard to get the shape accurately, and secondly, all the grinding is done with the steel at its thinnest, making it almost certain that you'll burn the steel See Figure 14. The only way to recover from burning the tip is to re-harden and temper the steel.

Instead, shape the curve on the grinder with the tool held perpendicularly to the wheel, quenching frequently. Only when it is fully shaped should you bevel the finished shape, Touch edged tools up frequently with a whet stone as you work.

9.3.3 A Step Backwards

Working over the surface with the straight chisel will clarify the shapes visually, and you'll undoubtedly discover areas where you want to take off a lot more stone. Switch back and forth between a fine tooth chisel and flat chisel for this. If you have a good idea of what you're after, the size of the errors you discover should shrink rapidly as you approach the final form. Notice the subtle changes that took place between the piece as shown in this section and the next, particularly in the heel and thumb of the left hand and the left side of the skull.

9.3.4 The Finest Carving

At the stage shown in Figure 9.7, most of the carving has been done with punches and chisels that are struck with a mallet or used with air power. Rasps have been used to some extent on big curves like the skull, and an electric drill, followed by the die grinder, has been used to get into deep recesses such as the eye sockets, under the hand, and the zygomatic arch of the cheek bone. The basic shapes have all been defined at this stage, but the surface is blank, with

no details such as dimpling, creases, muscles, tendons, and veins. At this stage, there is about a 1/16-inch of stone left to remove from the surface—it's time to put down the hammer and chisels and switch to rifflers and push chisels. Note that many sculptors would use rasps and rifflers for the work that is being done here with push chisels. It's a matter of taste—either method works. The biggest advantage of push chisels is that unlike rasps, they do not leave scratches that must be sanded out. The subsequent sanding that must be done on a rasped surface removes enough stone to significantly change the shape of the surface, and how it interacts with light. When using a rasp, you allow for this, of course, but sandpaper is a relatively blunt instrument for this kind of delicate work, and slow.

The basic push chisels should have the corners ground slightly round so as not to incise step-like lines at the edge of the cut. The most useful ones for softer surface modulations will have a roundel shape. For large outer curves, a straight edge is better. If you are right handed, you'll hold the metal part of the tool with your left hand, and the handle with your right. It's usually best to hold your upper arms tightly to your body and use your body and shoulders to drive and control the tool, rather than extending your arms. This gives you more control and power, and makes the tool less likely to lurch out of control and gouge something. Don't try to take much stone at a time, just shave it away.

The critical things are that the cutting edge should have an angle of close to ninety degrees, rather than the acute angle of striking chisels, and that they be kept sharp. Touch up the edge on the water wheel every few minutes, as necessary, and don't hone them. They work better just as they come off the grinding wheel.

Keep the work wiped clean with a damp cloth, and use good lighting. At this stage, even minute changes to the surface have a huge visual effect because of the way they can move the shadows around.

Almost all of the modulations to the larger surfaces of this piece, including structures like creases, veins, fingernails, and tendons were done with push chisels. Rifflers were used primarily in smaller areas, and places where there are tight curves. Carving inside cavities and tight spots, such as inside the nose bones, was done mostly with small silicon carbide stones in the die grinder or Dremel tool. At this point, carving is no longer about mass, but entirely about how light hits the surface; tiny gradations of the surface move shadow and highlight around almost like painting. Therefore, it is important to use lighting as good as you'd want in a gallery.

Grinders are used only for carving small details and in tight spaces—using any kind of power tools on the larger surfaces will grind the life out of your piece when carving at this scale. Push chisels remove stone quite quickly, in a very well-controlled way, and will usually usually shave off the full depth of scratches from a rasp in one stroke. Another danger of using the grinder at any stage is that the eye easily picks up the characteristic semi-circular curves that result, and senses the use of the tool. For no obvious reason, while tool marks from the punch and chisel can enhance the sense of the stone-ness of a carving,

Figure 9.7: The piece mostly carved and ready to finish.

Figure 9.8: The surfaces have been finished primarily with the push chisel, and the piece is wet for inspection.

evidence of the power tools always seems like a hack.

Decisions must be made at this point about the final surface: will it be polished, tooled to the natural matte surface of the stone, and will the final work any exhibit tool marks? The push chisel leaves a matte surface that is about as smooth as paper. For some pieces, this is may be as smooth as you want it, because some marbles become much more transparent when they are smoothed beyond this level, which can change the appearance greatly. Seeing into the stone obscures the surface modulation, hides details, and exposes internal variations in the stone. Notice the difference between the surface quality at this stage and how it looks in the final picture, when it has been smoothed a little further with sandpaper, exposing smoky streaks in the stone that were completely invisible beneath the matte finish. If this stone were fully polished, these streaks would be much more visible.

The picture below shows the piece sprayed with water. Almost the entire surface has been worked with a push chisel–there has been no use of sandpaper yet. The die grinder has been used in a few places, like the eye sockets and inside the nose area. The apparent shine is the damp surface.

At this point, the problem has ceased to be how to get the stone off, and become one of restraint. The stone begins to seem almost plastic because the surface can be modulated to show shadows and highlights so easily. Rinse the piece frequently, and view it wiped with a barely damp rag to expose scratches and tool marks. This final carving must remove all marks that you do not intend to leave. All bruises should be long gone by now, but you may still discover some. They show as milky areas under the surface.

If you're planning a smooth finish, you must shave down the stone until any bruises are completely gone—they run much too deep to sand away. The marble used in this piece is very hard and rather transparent, and shows bruises very easily. Wetting the stone revealed a bruise that had gone unnoticed with the stone dry—it can be seen in the picture in the middle of the top of the skull. It is nearly invisible when the stone is dry, but it won't be when the piece is smoothed further. This bruise is in too obvious a place to leave, and much too deep to shave away with the push chisel, leaving no choice but to revert to the chisel, and remove approximately an 1/8th inch of stone from the top of the skull. Even this did not entirely remove the bruise, but fortunately, the bone areas of this piece are not to be polished, and the matte finish makes sub–surface flaws much less apparent.

The teeth have not yet been carved.

9.3.5 Finishing

If the preceding step has been done thoroughly, there should be little to sand. Sanding, beyond what is necessary to unify the surface for polishing is to be avoided—it wrings the life out of a piece. If the work with push chisel and rasp in the preceding step is careful enough, very little unevenness should remain on the surface than cannot be removed quickly with 120-grit aluminum oxide paper.

Follow the carved contours very carefully lest you flatten out the fine detail. If you're familiar with finishing wood, don't be mislead by the coarseness of 120-grit paper. It leaves a better surface on marble than it does on wood, and may even be smooth enough for the final surface of many pieces.

Stopping at 120-grit has the advantage of obscuring minor sub-surface defects and hiding slight color and darkness variations inside the translucent stone. For subtly carved surfaces, suppressing the details of the stone with a matte finish highlights the surface detail. The flesh in this piece will be finished smoothly, but without gloss.

This particular marble can yield an almost spooky flesh, because of its translucence, but if its finished too highly it begins to show too much of the smokey internal variations.

The bone will have a different texture from the hands in the finished piece. The realistic bone texture on the face will be achieved by texturing the chiseled surface slightly by just touching it with a very small rotary grind stone. Marble isn't perfectly homogeneous—it is made of tiny crystal grains in a softer matrix. When abraded with something too small to bridge across the hard grains, a very slight lumpiness emerges because the softer stone wears away faster. For this marble, the lumpiness is so on the scale of very fine sand, and it looks very much like the texture of bone. A small light stone was allowed to barely dance on the surface. A similar effect can also be achieved with a rotary wire brush on a Dremel tool, or even by striking the surface with a the bristles of the brush. The wire bristles break off and can be thrown quite hard, so wear your glasses.

The teeth were entirely carved with a very sharp 1/8-inch carbide-tipped lettering chisel, used without a mallet. The outline of each tooth was scratched in with the corner of the chisel, and then the chisel was simply pushed up to the scratched line repeatedly to shave out the shape of the tooth. Despite the fine detail, this was quick—about an hour. The view below shows the piece with everything that will be sanded finished to the 120-grit level.

Don't think of 120-grit sanding as polishing—think of it as the finest level of carving—a swipe with this grit removes a few 1000ths of an inch of stone, and the effect can be very visible, greatly altering the way shadows fall on subtle features. Vary the lighting as you work to be sure of the surface. This is the step that determines the final exposed surface of the stone. Tear the paper into strips with a straightedge (sandpaper destroys scissors). Fold the strip so it has several layers. The sandpaper on the back will provide enough traction that you can retain fine control when you push it. Do not use any kind of rubber block, as it will ride over all the details. The folded sandpaper grips you skin nicely, but after a while it scours the skin off your finger tips leaving an painful raw strawberry. To avoid this, wipe your finger tips with white or yellow carpenters glue, like Elmer's Wood Glue. Blow on the glue until it is tacky, and then dust them with fine sawdust or marble dust. Repeat a few times until you have tough skin that will protect your fingers all day. When you're finished, it peels off like sunburn or washes off with water.

Keep inspecting for scratches, dings, and steps left by the push chisel. Further sanding with finer paper will not remove them—you must get them all

out now. Use light across the piece to highlight the surface. If you started with 100-grit, repeat the process with 120-grit or 150-grit aluminum oxide dry paper. It should be faster this time, but continue to be scrupulous. If you want the surface smoother still, switch to black wet-or-dry paper, starting with 220 grit. Keep a bowl of water next to the work to dip in, and keep it wet, refreshing the water often. You can feel when your exposed piece become dull, so change often; wringing every square centimeter of smoothing out of a one dollar sheet of sandpaper is a poor use of your time. Unfortunately, the glue trick doesn't work with wet paper, which still wears away at your skin. But if you've done the first steps carefully, the 220 step should be quick. When you're done, wash again and examine as before.

Scrubbing with 220 can still remove a noticeable amount of stone, so its important to keep your eyes open and follow the contours. Beyond 220, the effect of a single sanding is very small, so one need not be quite so scrupulous. Proceed this way through the grits: 220, 320, 500, 600, 1000, until the surface is as shiny as you want it. 1000-grit leaves it almost glassy. You can roll the polish back by reverting to a coarser grit if you find you've gone too far. Finishes similar to 1000-grit were popular for flesh in the Renaissance and Baroque. The Christ in Michelangelo's Roman Pietá has a finish somewhat finer than 1000-grit (It was actually done with shark skin, not sand paper). This piece will have a 600-grit finish for the flesh, and 120-grit for the dome of the skull. The texturing of the face was described above. To give it a finished appearance, it was gently scrubbed with 320 grit paper that has already been used and is thus very flexible. This gives a very slight luster to the highlights without removing any of the texturing.

No areas of this piece were polished, but after the 1000-grit step, paste rouges can be used to obtain a mirror finish. Like sandpaper, they come in a range of grit fineness.

Marble stains and yellows easily when touched, and people cannot keep their hands off it. Treat the finished washed and dried piece with marble sealer.

Figure 9.9: Completed. The stone is dry.

Chapter 10

Repairs and Cleaning

Repair and restoration of fine art is a specialized and very technical field, but artists often get asked to do it, and frequently need to make minor repairs to their own work. When working with stone, as far as possible, always test the proposed repair procedure first on a sample of the same stone— glues and fillers can give surprising results for many reasons, including the porosity and translucence of the particular stone.

Repair techniques for interior and exterior stone are quite different from repairs to marble. Exterior stone is subject to precipitation, large changes in temperature, and a variety of chemicals, both organic and inorganic. In addition to this, non-igneous stones are permeable, with water carrying various dissolved salts and minerals passing in and out of the stone. For this reason, exterior stone is usually repaired with lime-based cements and grouts, which tend to have properties more like stone. These cements and mortars are also designed to be physically weaker than the substrate they are repairing, so that future repairs are not made more difficult. Epoxy and acrylic based cements tend to be impermeable to water, resulting in a variety of destructive dynamics.

10.1 Breakage

Even completely sound marble is very fragile—it breaks as easily as a clay pot. Pushing a chisel into a tight space is a common cause of breakage.

Marble and other carbonate stones are also prone many kinds of flaws that may or may not be visible on the surface. There can be a single well defined cleavage line; bands of weak crystallization; inclusions of foreign matter; or regions that are riddled with invisible cracks. Inspect the stone very carefully before starting, wetting the surface with a spray bottle as you go, to find any flaws that reach the surface. Even otherwise invisible cracks will suck in water, while the rest of the stone has a sheen. Weak spots can sometimes be spotted by slight milky tone, or by an area of the surface that absorbs dampness. Just as one can hear that a bowl or plate is cracked, tapping on the stone and listening

for irregularities in the tone can reveal flaws.

10.1.1 Super Glue

Minor detached pieces can often be simply glued back on with cyanoacrylate "super-glue.' These glues work well for breaks that mate perfectly, and leave almost no glue line. Make sure the broken surfaces are absolutely free of any dust or loose chunks that may interfere with a perfect fit. The attached piece should be clamped lightly in place overnight. The clamp should be elastic pressure like rubber bands. It does not require a great deal of pressure, but it is important that the pressure be even.

The glue will stick quickly, but it won't be truly set hard for a while. A tight joint in an area that has not had a final sanding and polishing will be all but invisible when the surface is finished. Don't use a chisel on the repaired piece. Try to limit work on the repaired area to filing and sanding.

10.1.2 Filling Glues

For worse injuries, where some stone is missing, filling can be used. In former times, wax and various lime-based plasters were used as fillers. Modern materials give better results, but there are several considerations. Fillers must match not only in color, but in translucence, luster, etc.

The first major choice is between an organic and an inorganic binder. The organic binders are typically epoxies, polyesters, or other resins that form a matrix to bind together particles of bulking agent pigments. They may harden by either evaporation, e.g., methacrylate in acetone; catalyzed reactions, e.g., epoxy and polyester; polymerization, e.g., acrylic modeling paste; or thermosetting , e.g., polymethyl methacrylate (PMMA) resin. For outdoor use it is important to confirm that the resin is light-fast, as some resins are subject to yellowing and/or deterioration in sunlight. Use resins formulated for art repair—hardware store epoxies are risky, because for one thing, they are not necessarily light fast.

The inorganic binders are typically plaster-like, being based on gypsum plasters like plaster-of-Paris or Hydrocal, or or lime cements, like white Portland cement. The inorganic binders are usually used in architectural and other outdoor restorations.

Many kinds of filler materials can be used, depending upon the stone and the nature of the repair. Dust ground from the same stone is the obvious base for a filler, but probably will not match particularly well, because of refractive properties of the plastic binder, and the altered physical structure of of the mineral itself. Even stone from the original will probably have to be tuned up with other additives to adjust the appearance of the filler. The mix may include fumed silica, glass microspheres and micro balloons, chalk, titanium white and other inorganic pigments, and pulverized natural minerals such as mica, to provide a variegated appearance. There is no one recipe—every stone will require experimentation to get a good match. For consistency of test and final result, unless you are weighing your ingredients with Heisenberg-like precision,

as you get close to a match, make the full batch, mixing it all very carefully, and adjusting the entire batch, testing only a sample.

For repairs to marble, organic binders will usually be chosen, usually epoxy or polyester. A transparent organic binder will probably also be best for for granite and any other hard stones that have visible structure. For limestone and other opaque stones, you may do better with a lime-based filler.

Translucent fillers like micro balloons will work better for marble and other translucent stones; more opaque fillers such as fumed-silica and chalk may not give the needed translucence. By the same token, opaque fillers should work better for limestone. For granite it may be necessary to add macroscopic aggregates to simulate the original. Eleanora Nagy's [nagy 98] laboratory report on the issues provides a good overview of the properties of various fillers.

No matter what the choice, finish sample repair all the way to completion, including polishing. Color differences, differences in the transparency, and other properties of fillers and substrates may not show up until the final polishing. For very small repairs, acrylic modeling paste works well.

Epoxies and polyesters may soak into the surrounding stone leaving a band of discoloration. To prevent this, you can seal the boundaries of the fill with a non-migrating sealer such as *Paraloid B-72.* Test the sealer too, before applying it in a visible area.

For major repairs, particularly to outdoor work, the elastic properties of the patch and resistance to cycles of freeze and thaw, etc., may be important. These concerns are beyond the scope of these notes and must be researched in the literature it they apply.

Conserving, restoring, and repairing art is a fast-evolving field, and techniques and materials improve constantly. Therefore, modern conservators are concerned that repairs be reversible. For this reason, it is advisable that the repair material be physically weaker than the substrate so that it can be removed mechanically. This may or may not be of concern to the working artist. Griswold and Uricheck [Griswold 98] give an excellent overview of the issues. CathedralStone, in Hanover Maryland, sells a wide variety of high-tech materials for repair and stabilization of stone sculpture, particularly exterior work.

10.2 Major Breaks

For large pieces, say, a head separated at the neck, you may need to to insert one or more metal pins. Use steel, rather than brass or aluminum dowels, because the rate at which steel expands and contracts with temperature change most closely matches that of marble. For outdoor use stainless steel or titanium may be more suitable.

Slight differences in the expansion rate of the two materials, measured by a quantity called the "coefficient of thermal expansion" (CTE) will be absorbed by the elasticity of the stone and adhesive, but combining materials with CTEs that are too different could result in opening the break if the piece is later exposed to extremes of temperature. Corroding iron can expand enough to

break the surrounding stone.

It is difficult to get a precise alignment of the holes because of the irregular surfaces; fortunately, perfect precision not really necessary. To locate the holes, drill tiny pilot-holes first in the less easily moved piece. A nail with the head clipped off is set in the hole with the point sticking up very slightly. Align the other piece and press down to make a mark. Now drill the real holes, aligning them by eye as well as you can.

The holes in what will be the bottom when you reassemble it should be a little bigger than the dowel to allow a loose fit, while the holes in the top can be the right size.

Test fit with dowels in place to insure that the alignment is good. If necessary, enlarge the hole that will be on the bottom when you make the final assembly. This need not be the on the bottom with respect to ultimate orientation.

Fix the dowels in the upper piece (the snug fit) first. Be sure you have wetted both surfaces and leave no epoxy pushed up above the surface to interfere with a perfect fit.

Let the epoxy cure. This will prevent the epoxy from draining out when you do the final assembly. Unlike many glues, epoxy fills gaps well, hardening into a tough, rigid plastic.

Re-test to make sure the new fixed alignment still allows the pieces to come together perfectly. You may still need to ream out the hole(s) slightly and blow them clean again. Make sure everything is prepared in advance—the work piece should be blocked up solidly in a convenient position, sandbags or other blocking should be handy for securely aligning the piece to be attached.

Don't try to get this stuff together after you mix the epoxy!

When you're ready to re-attach the piece, wet both surfaces of the dowel and hole with enough epoxy to fill the spaces, but not enough to gush out a large volume. Wet the surfaces of the stone that will touch. You want the bottom hole to fill, but not overflow, when you let the pieces come all the way together. As you set the piece down slowly, add or remove epoxy as necessary with a small brush as the pieces close. Epoxy does not leave the invisibly thin glue line of cyanoacrylate glue. If possible, it is best to use cyanoacrylate cement to glue the surfaces and reserve the epoxy for seating the dowel. If epoxy is to be used to adhere the surfaces, it must be a filled epoxy. Pure transparent epoxy filling the gap will show as a black line, because you can see into crack. Filler diminishes this effect, but may not eliminate it entirely, so a real test requires joining sample pieces, not just preparing dabs for a color test. Missing chips at the edge of the repair can be filled. Leave a little above the surface to shave down, but beware that the filler and the stone will not be equally hard, so care must be taken when finishing the surface.

10.3 Cleaning

Marble and limestone are porous, absorbing and transmitting liquids and gasses like a sponge. And like a sponge, it's difficult to remove every trace, once a stain or pollutant has penetrated.

Marble should be cleaned with cotton balls, slightly dampened with distilled water and a 2% mixture of non-ionic detergent. Non-ionic detergents, such as Kodak Photo Flo are used because they are of neutral pH, and thus do not produce salts when in contact with minerals. They are effective, yet low-foaming.

A small amount of artists-grade mineral turpentine, a.k.a, white solvent, a.k.a. naphtha, can be added. Do not use "gum" turpentine, which is a very different kind of solvent made from pine sap. This solvent acts as a degreaser, removing oils and waxes that are too resistant for the detergent. Older pieces can have a patina that should not be disturbed—wipe gently, rather than scrub, and rinse repeatedly.

Don't use any other household cleaning products, as they often contain either abrasives or chemicals that are bad for the stone. Ajax and similar cleansers contain powdered quartz which is much harder than marble, and will literally grind away the surface. Even Bon Ami contains feldspar, which is softer than quartz, but still harder than marble.

Removal of stains should not be attempted without expert knowledge. Chemicals capable of bleaching out the stain are likely to be destructive, and chemicals that dissolve the stain may also move and spread it. Resistant dirt and stains can be removed with "poultices", i.e., pastes of absorbent clay and other materials to soften and draw out stains. Prolonged exposure to bright sunlight will bleach out many stains naturally.

Chapter 11

Miscellaneous Issues in Carving

These sections are concerned with advanced issues in stone carving, both technical and aesthetic. The sections are as follow:

- Struts 11.1 How sculptors leave stone bridging in place to support delicate structures while they are being carved.
- Eyes 11.2 How sculptors have dealt with portraying the non-sculptural aspects of the eye: transparent structures, sparkle, tears, etc.
- Flesh 11.3 Issues in carving realistic flesh and skin. Age of the subject, wrinkles, etc.
- Multiple Pieces 11.4 The practice of assembling a sculpture from multiple pieces of stone vs carving from a single block.
- The Drill 11.5 The use of the drill in carving is ancient and has at times been controversial. Dangers of overuse.
- Indirect Carving 11.6 A survey of the history and issues associated with carving stone by mechanically copying a model, having a model copied by others, etc. Mechanical pointing, the use of assistants, a survey of the history of the practice, the Modernist doctrine of direct carving, Hildebrand, CNC. The awkwardness of conventional ideas of originality as relate to sculpture.
- Naturalism and Verisimilitude 11.7 Realism comes in many flavors. The attempt to repoduces a faithful image of a living person has been surprisingly limited over the centuries, but flourished in the pre–WWI years. Naturalism v. 20th and 21st C. hyper-realism. Life casting, death masks, etc.

11.1 Struts

When carving delicate areas such as limbs, fingers, and ears, carvers leave struts, i.e., bridges of stone, in place to support them until carving is complete. Bridges take advantage of stone's greatest strength, which is resistance to compression. Just as a huge stone can be split by a relatively trivial expansive force applied by wedges, appendages that stick out can be snapped off very easily, because of the leverage developed when force is applied from the side. Even a slender strut added behind the point where pressure might be applied adds tremendous strength. When planning bridging, rely only on the compressive strength of the stone, just as one would with a brick column in a building.

Sculptors of other ages routinely left temporary bridging in place, not only for the duration of carving, but for shipment as well. The bridging was removed, and the attachments cleaned up, only after the piece was safely installed.

Figure 11.1 is a detail of *St Sebastian,* from the tomb of Lesa Deti in the Aldobrandini Chapel in Santa Maria sopra Minerva, Rome. It was installed, but left unfinished by Nicolas Cordier, apparently because of a dispute relating to payment. Several features are not quite complete, but most notably, bridging was left in place between the fingers of the upraised left hand. Note also the use of the branch to which the saint is bound as permanent bridging to support the cantilevered weight of the arm.

Figure 11.1 shows a strut that was probably intentionally left in to support an otherwise fragile thumb in Daniel Chester French's allegorical group "Asia," which stands in front of the Custom House in New York.

Bridging should not be chiseled out, but should be sawn out carefully, with a fine toothed hacksaw. Chiseling it out would result in levering the supported piece, possibly breaking it off, and the use of a grinder to cut through the bridging would be risky. Binding of the grinder could result in the same kind of strong outward pressure as would be produced by chiseling, possibly enough to snap off the reinforced piece.

In classical sculpture, substantial bridging was frequently left in permanently, to support cantilevered masses which might eventually succumb to gravity even if they survived carving. Such bridging is usually found in positions where it would not be easily seen from vantage points available when the sculpture was in place. The marble *Statue of a Wounded Warrior,* a Roman marble copy (c. CE 138-181) of a Greek bronze (c.460-450 BCE), seen in Figure 11.1 shows the remains of permanent bridging that would probably have been obscured in the intended installation. This sculpture originally also had a bronze spear and shield attached. Permanent sculptural bridging is often disguised as an element of the composition. The ubiquitous tree stumps so often found in figure sculpture are usually structural. Drapery, weapons and other elements often perform a similar function. In the case of the warrior, the original bronze would not have required the additional support of either bridging or the tree trunk.

Figure 11.1: Nicolas Cordier, "St. Sebastian", marble, Rome, Sta. Maria sopra Minerva, Aldobandini chapel (detail). Struts left in place on raised left hand.

Figure 11.2: Daniel Chester French, "Asia", Limestone, the Custom House, New York, NY (detail). Strut left in place under left thumb.

Figure 11.3: *Statue of a Wounded Warrior*, Marble (detail), Metropolitan Museum of Art, NY

11.2 Eyes

The eyes are the most obvious element of a human or animal figure for which properties such as color, gloss and wetness, which have no shape, are essential features. These features are critical components to the expression of emotion and aliveness in many ways:

- Sparkling shininess in the eye is a key indicator of happiness, alertness and attention. Sparkle is generated by both moisture and motion.
- Moisture is obviously a clue to sadness when it appears as tears, either flowing or brimming.
- A rheumy, thick look in the eyes is suggestive of age, depression or illness.
- Dilated pupils, particularly in women, are indicative of passion.
- Constricted pupils give an appearance of ferocity or focused thought.
- The quality of light reflected by the pupils can an important clue to the implied surroundings of the subject, e.g., is the subject indoors, and are multiple sources of light implied?

The Greeks painted or otherwise colored most sculpted marble (except for the flesh of women) but we know little of what they actually looked like, because few examples of polychromed Classical stone sculpture remain even partially intact. Examples of bronze sculpture exist with colored stone and glass inserts used for the irises and pupils. Painted-on details of lashes, eye color, and skin treatments of rubbed gold can still be detected. From these, and from chemical traces of pigments detected on ancient sculpture, it is inferred that smooth, blank eyes of classical Greek figures were almost certainly realistically painted.

The Roman tradition of sculpture, when not imitating the Greek, placed greater emphasis on naturalism and individual character. Roman figures, too, were often polychromed, but indications of the particulars of character and emotion, including those of the eyeballs are far more developed, especially in portrait sculpture. The Romans frequently carved the bulge of the cornea and indicated the depths of the pupil by drilling. They did not, however, often attempt to carve features of reflection and moisture, despite their intense concern with naturalism. These details are unnecessary when the stone surface is intended for painting.

The revival of ancient forms that characterized the Renaissance did not include polychromed surfaces for figures. All color had long since been lost from the then-known examples, as it had from almost all surviving classical buildings. The ancient traditions of sculpture were revived in a systematically distorted form, because they were largely divorced from the coloring and decoration that they were originally designed for. Thus, the Renaissance, Mannerist and Baroque masters increasingly added liveliness to sculpture of the face by developing techniques for “sculpting” shininess, wetness, color and other non-massive features.

Figure 11.4: Christophe-Veyrier, *Bust of Marquis Jean Deydé*, detail, 1684, Metropolitan Museum of Art, New York

Figure 11.2 illustrates an interesting example of the rendering of complex purely visual highlights sculpturally. Note the complexity of the reflection suggested by the carving in the iris, suggesting that the subject is indoors, in a darkened environment lit by multiple sources. The physical structure of the eye, the vivacity of the subject and his embedding in a complex world are deftly portrayed. The cornea is slightly recessed behind the sclera of the eyeball, faintly suggesting the *arcus senilus* characteristic of an aged subject. This effect is an almost graphical use of carving, because in life, the cornea bulges from the sclera. Note also that despite the representation of individual hairs in the eyebrows, the eyelashes are not directly rendered at all, but are suggested by the shadows cast by the excessively thick upper eyelid, which also contributes to the slightly rheumy, aged appearance of the eye. The effect in sculpture seen whole is of extreme realism, but the details taken individually are highly unrealistic. This level of visual complexity seldom appears before the Seventeenth Century, but sculptors even in the Classical world carved features, such as the iris, that have no existence in pure form, and the practice was common in the Renassance, even among purists like Michelangelo.

The handling of the eyes in the Bernini bust of Scipione Borghese, in figure **??** is also interesting. The double ring incised around the iris does not actually exist in the human eye, but combined with the depressed and roughened surface of the iris, which swallows light, making it seem to be dark a distance, and the raised stone gleam at the level where the cornea would be, it adds to the strong impression of the clarity of the eye. As in the Christophe-Veyrier bust, the eyelashes are not represented directly, but the thickened eyelid produces a shadow that gives the illusion of eyelashes. On the left we see how these small effects come together to make the image appear to be startlingy alive when seen at a more natural viewing distance. The artist has literally sculpted light, both in the eyes and in the skin.

11.3 Flesh

The key to carving realistic flesh, particularly where flesh touches flesh, is making the wrapping, folding and dimpling of the skin believable. Skin, together with the attached fat behind it, has thickness—when it folds or creases outwardly, there is a minimum radius to the curve of the surface that implies this thickness; the smaller the radius, the thinner the implied skin. Inward folds don't have to wrap around a layer of fat, so the radius of curvature can be tighter.

The radius of the minimum curve tells much about the subjects age for a given location of the skin on the body. Toddlers have a thick layer of fat almost everywhere, so the radius is large. There can be no tight curves, so everything is smooth and plump; you can't really pinch a fold of toddler's skin. The eye is very good at sensing structures wrapped in skin and the visual correctness of the way the skin clings to the substructures. Except in small children, female skin retains a thicker layer of fat than male skin of similar age.

Thus, sculptors control the appearance of age by manipulating the minimum curvature of the surface of the skin. For adult men and women, skin is thinner on the face and hands, with older the person, the skin in these areas becomes almost paper-thin, especially on the hands. Wherever subcutaneous features of any kind need to be indicated, the maximum curvature of the skin determines how much detail can be seen on the surface. This is why the hands and the neck are said never to lie about age—these areas of the body contain a great deal of subcutaneous detail and they lose fat early.

Where a crease ends, the skin dimples up slightly in the same characteristic radius to take up the slack. The curvature of skin may always be less than the critical radius, but it must never be greater, or it won't look right. The critical radius varies from place to place on a given body, but it only changes abruptly in a few places, such as around the eyes and to some degree, the neck and hands, especially in older people.

Older people's skin loosens, in addition to having less subcutaneous fat. Loose skin is a reliable visual indicator of age—young people never have it. Face lifts tend look increasingly unnatural as the subject ages, because they

remedy the looseness of the skin but don't replace the fat. Without enough fat, the taut skin begins to look unnatural. The same holds true for sculpture—the looseness of the skin and the implied thickness must be in sync.

Whatever the surface features of flesh, one of the most effective ways to model the subtle surface is with square-cut push chisels, as described in Section 6.2.16. These tools permit the most delicate modulation of the surface without the need to allow for a margin for smoothing.

There are a number of ways to deal with the finish on flesh. Ancient works tend to have a flat, opaque, matte finish because the marble was usually uniformly bruised across the entire surface. They rarely show fine detail, although work in the Roman style, as opposed to Roman work imitating Greek, often has wrinkles and facial blemishes, but not minute detail.

Neoclassical works are often finished quite smoothly, but the sculptors scrupulously avoided bruising the stone because they were not to be painted.

Later Nineteenth Century works often have a more complex finish, by which the skin is given a richness through carful modulation of surface scratching. In many pieces, rasp marks and the marks of relatively coarse grinding with stones are not completely obliterated before the surface is ground with fine abrasives. This gives a rich, deeper look to skin, because of the slight surface sparkle, the white at the bottom of the scratches, and the scattering of light below the surface caused by the scratching. This is described more fully in Section 8.1. It is not a universally used technique, and it works better on some kinds of marble than on others.

Bernini's handling of flesh in the portrait of Scipione Borghese, shown in Figure 11.3. is a fine case of directly representing the fine texture of the skin. Notice on the right, the rendition of the pores on the nose, the very fine wrinkles in the cheeks, and the slight creasing of the skin just below where the jaw meets the neck. These features are an order of magnitude or more smaller than the smallest directly carved features, such as the bunched skin and wrinkles around the eyes.

The finest wrinkling appears to have been achieved by finishing over rasp marks with a much finer abrasives. The creases in the skin of the neck seem to incised one by one below a more finely smoothed surface, and then the surfaces ground smoother.

The appearance of pores seems to have been produced by lightly finishing a surface that has been pre-textured, perhaps by a light impact with some kind of grainy stone. (Another way to achieve this kind of texture is to tap the marble with the bunched bristles of a wire brush. The impact of the tiny wire points scours out the softer material between crystals, leaving a stippled but smooth surface.) The impression of all of these textures is heightened by contrast with the glossy surfaces of the cardinal's satin vestment.

Figure 11.5: *Portrait of Cardinal Scipione Borghese* 1632, Gianlorenzo Bernini, Galleria Borghese, Rome

11.4 Multiple Pieces

Historically, and especially in modern times, many sculptors and critics have been horrified by the idea of constructing a statue from more than one piece of stone. Like indirect carving, it seems to go against the essential nature of the stone. Yet the sculptors of Greece and Rome did it routinely, often attaching arms and legs if a sculpture would otherwise require an excessively large block. The Romans went even further, and often joined marble heads to wooden dummies that were draped in real cloth robes.

It is important to remember that the weight of the block from which a sculpture is to be carved does not increase in proportion to the scale of the sculpture, but by the cube of the scale. Therefore, if you double the size of the sculpture, the weight of the implied block increases by eight times. To make this concrete, block that could contain a life-size figure might be 2.5" x 3.5" x 6.5", or about 57 cubic feet, and would weigh five tons, which is about twice the weight of a Chevy Suburban. The same figure at twice life size would require a block 5.0" x 7.0" x 13.0", which would weigh 38 tons–as much as a tractor-trailer car-carrier, plus a full load of eight Suburbans.

When a sculptor is pieced together, not only is the amount of material greatly reduced, but many other problems reduced in proportion: moving and installing, the risk of breakage or encountering concealed flaws, etc.

Large reliefs were (and still are) frequently carved as separate panels, and outdoor pieces and fountains are often made of blocks stacked together with no attempt to hide the seams. This approach seems to work best with rougher stones such as limestone.

Bernini sometimes used multiple pieces where a single piece of stone would be too large or unwieldy, and usually relied upon concealing the seams behind overlapping drapery or other features. Bernini's *Longinus,* seen Figure 11.7, is about four meters tall, and would have required an immense flawless block to carve in one piece. Instead, it is patched together from four pieces. The main body, the extended arm, the drapery on the front side, and the cloak on the left are all separate pieces. *Longinus* is one of four pieces of similar scale, each by a different sculptor, that are positioned near the base of Bernini's *Baldacchino* in St. Peter's. None of the four are carved from a single block.

Likewise, the sword held by Perseus in Canova's *Perseus Triumphant,* seen Figure 11.4, was carved separately and attached, not so much because it would have increased the size of the block, but because it would have been very difficult to carve in place.

One important consideration in using multiple pieces is that you cannot chisel continuously across a joint in the stone because the chisel approaching an edge from the inside will tend to blow out large chunks. Therefore, the pieces to be joined must be carved very accurately and only ground or rasped at the joint. It is also necessary to plan in advance for assembly, as points for lifting must be allowed for, and connecting pins should be in place before carving starts.

Ancient sculptures were often connected with wrought iron pins. Unfortunately, rusting metal can swell enough to burst the stone, as seen in Figure

Figure 11.6: Antonio Canova, *Perseus Triumphant*, detail with joined stone, c. 1790, Metropolitan Museum of Art, New York

Figure 11.7: Gianlorenzo Bernini, *Saint Longinus*, 1631-1638, Basilica di San Pietro, Vatican

11.8. Another problem with joining stone rigidly is that iron and stone have different coefficients of thermal expansion, i.e., temperature changes expand and shrink them at different rates. Therefore, even in the absence of corrosion, large or sudden temperature changes can cause either the iron pin to expand or the stone to shrink around the pin enough to stress the stone. Setting pins in epoxy instead of the traditional lead can eliminate the corrosion problem, but epoxy has a much higher coefficient of expansion than any metal or stone, so it is not good for joining stone for outside sculpture. For outside sculpture, it is better, if possible, to design sculpture that is entirely held together by gravity and cement based mortars.

11.5 The Drill

The drill is used by sculptors in several ways: to project reference points into the block, to honeycomb stone to make it easier to remove with a chisel, and as a carving tool in its own right.

While drilling is indispensable for deep or narrow cuts, drilled holes in a finished piece it can be visually disturbing, particularly if there are multiple holes of the same size. It may be that the ubiquity of manufactured goods has made the modern eye more sensitive to the unnatural look of perfectly round drill holes, because many excellent sculptors from the 18th Century and earlier seem to have been oblivious to the effect, and routinely left undisguised drill holes in sculpture, particularly in curls of hair.

Figure 11.5 shows the undisguised use of the drill in the hair of *Flora*, by Pietro Bernini, in the execution of which he was assisted by his eighteen year old son, Gian Lorenzo Bernini. The younger Bernini's *A Faun Teased by Children*, seen in Figure 11.5 carved the same year, shows similar exposed drill marks. Perfectly round holes or fractions of cylinders tend to catch the eye very easily, giving carving a carving a riddled appearance when used to excess.

Figure 11.5 shows both the disguised and undisguised use of the drill. Many uniform-sized holes of two different sizes are visible, sometimes in the center of curls, and sometimes between curls. The curls are carved as helixes around drilled holes which have been disguised with varying degrees of success. Most of the spaces between locks are also carved by drilling a hole at each end of the gap, and then cutting a slot between the two holes by drilling a line of holes and then clearing out the remaining webbing. In some places the sculptor has taken trouble disguise the circular holes, and in other places they are simply left raw. Note also that the drill was used to undercut the stone in a number of places around the collar and cravat.

This piece also shows an unusual use of the drill on the cravat to render the tight folds in the silk. A fine drill bit was apparently used almost horizontally, and the stone subsequently removed parallel to the direction of the drill down to about half way through the holes, creating undercut channels. Particular care must be taken when the drill is used as a rough carving tool to honeycomb out a deep cut into a narrow space. This approach can go wrong in several ways.

Figure 11.8: *Fragment of grave marker*, Greek, c. 5th C. BCE, Metropolitan Museum of Art, New York

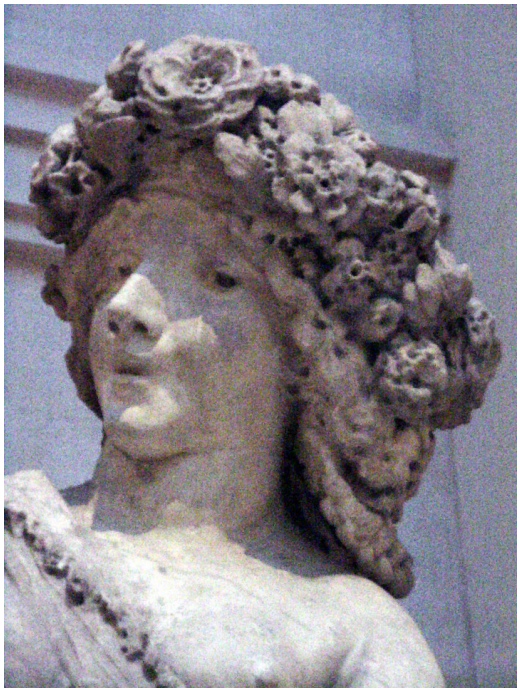

Figure 11.9: Pietro Bernini, *Flora*, detail, 1616, Metropolitan Museum of Art, New York, detail.

Figure 11.10: Pietro Bernini, *Flora*, detail, 1616, Metropolitan Museum of Art, New York, detail (left) Gian Lorenzo Bernini, *A Faun Teased by Children*, detail, 1616–1617 Metropolitan Museum of Art, New York, Marble, H. 52 in. (right)

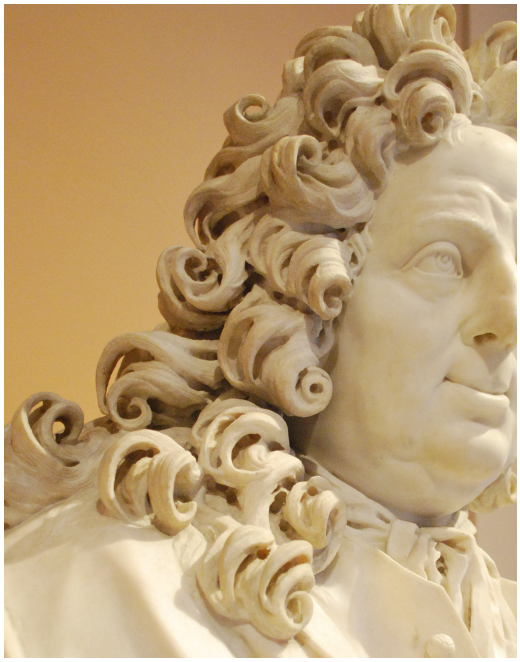

Figure 11.11: Bernardino Cametti, *Bust of Giovanni Andrea*, detail, 1725, Metropolitan Museum of Art, New York, Marble

First, if the holes are drilled too close to each other, a drill breaking through the wall of the preceding hole is likely to wedge, and the momentum of the spinning motor can burst the stone. The second hazard is that subsequent use of a chisel to clear the remaining stone can easily develop enough outward force to split the stone. Attempting to break the webbing between two holes can have a similar effect. It is better to clean out with a flexible shaft grinder, or if the geometry does not work, to grind it out with a rasp. Prior to the invention of electric hand tools, this task was usually done with a running drill.

11.6 Indirect Carving

In many art media, for example, in oil painting, especially in the modern era, the creative act and the execution of the finished work are essentially the same thing. Regardless of the amount of prior planning, the placement of the elements is still being worked out and refined on the canvas until well into the process, and even after the painting has reached a point where the location and shapes of the major elements can no longer be changed signficantly, color, details, highlights and shadows, etc., continue to evolve until the painting is completed. The painting emerges from the manual process of the artist painting[1]. This is not true for all media, of course. At the other extreme, composers and architects create only precise specifications for work that will almost always be entirely executed by others.

Many sculptors, especially within living memory, have ardently believed that an artist should create directly in stone, as a painter does with paint; that the sculpture must emerge from a personal, physical struggle with the medium. Such a sculptor may work from a maquette, as a painter works from a sketch, but the true creative act extends throughout the carving.

At the other end of the spectrum are sculptors who consider the pure form primary, and the fact that it is expressed in stone a secondary issue, or even irrelevant. These artists typically first create in wax or clay an exact model of the finished piece. The original is then cast in plaster, from which it is copied into stone using mechanical measuring devices. Sculptors have always used assistants, but prominent figure sculptors of the late 19th and early 20th Centuries carried the practice to an extreme, using assistants for much of the manual work.

Michelangelo, who dominated High Renaissance sculpture, and is probably the most admired sculptor in history, worked exclusively directly, but Antonio Canova, nearly as promininet in the Neoclassical world as Michelangelo had been in his time, almost always worked in clay, and then, working with assistants, copied the a plaster casting into stone using mechanical measuring devices.

[1] The use of assistants and specialists, for instance, by Rubens, constitutes at most a very limited exception. Rubens ran multiple workshops employing many painters to produce his work. Each painting was minutely specified by Reubens, who prepared the drawings and executed key sections, and the assistants position was entirely subordinate to him, but the process was one of collaboration among unequals, rather than a case of the nominal artist specifying a work that could be fully executed by an arbitrary skilled workman.

Canova was not unusual in this respect. Extensive use of copying machinery and assistants was the rule in the early Nineteenth century, and by the later Nineteenth Century, the majority of prominent sculptors did not care at all about direct carving, and handed off much, often all, of the carving to assistants, or to outside contractors.

Each artist had his or her own way of working, but successful sculptors in the Victoran and Edwardian eras usually made clay originals in

$$1/4$$

or

$$1/2$$

scale. Skilled specialists enlarged the smaller scale model into a full size clay version, which was typically refined and adjusted further by the primary artist. From the full-size clay, a plaster version was made, again, usually by a team of specialists. Unless the piece had been commissioned, it was usually the plaster that was exhibited pending finding a buyer to commission the final version in either stone or bronze. Many sculptors, including Rodin for instance, deferred even the decision as to whether a piece would be executed in stone or in bronze until a purchaser made his or her wishes known, and in fact often produced the same piece in both media. Working in clay was overwhelmingly the rule in the Nineteenth Century[2] with only a few notable exceptions. As far back as the Renaissance, and perhaps further, sculptors and critics have divided into two camps on this issue, but at the heart of it is always the question of where the creative act occurs.

11.6.1 Direct vs. Indirect

At the lowest level, chiseling away stone is the same mechanical process for any kind of composition, but at a higher level, there is a fundamental technical difference between the carving of the relatively monolithic sculpture of early Classical Greece, or Modernism, and the carving of the more complex, fluid compositions of the Hellenistic period, the Late Renaissance, the Baroque, and subsequent periods. The difference is in how, and at what point in the process, the final form is determined.

The process of carving a monolithic form is like peeling layers from an onion; the surface shrinks towards the center, as layers of stone are removed. After the crudest roughing–out, the shrinkage tends to be fairly even. For such work, it is natural to carve from all sides, with the momentary state of the carving serving as an evolving frame of reference for judging what to remove next. For this reason, direct carving, like painting, both requires and rewards a constant focus

[2] For instance, the Piccirilli Brothers studio in the Bronx, NY, which covered a city block. The firm contracted carving for the majority of the prominent American sculptors of the day, and carved many of the most famous sculptures by late Nineteenth and early Twentieth Century New York sculptors,including Daniel Chester French's most famous works, Edward Clark Potter's Lions at the NY Public Library.

by the artist on the state of the entire piece throughout the process. This kind of direct carving has been the default choice for most sculptors in the Twentieth and Twenty-First Centuries.

For at least two reasons, however, it is not generally practical to carve complex figurative compositions in this way. The less interesting, but still compelling, reason is that complex pieces require a great deal more work, and indirect carving allows the uniquely skilled (and/or persuasive) artist to off-load much of the carving to people with more ordinary skills.

The less obvious reason is that the conceptual difficulty of direct carving increases out of proportion to the complexity of the composition. In the onion model of carving a single mass, points on the surface of a mass move only inward, toward the center of the mass, which tends to stay in a more or less fixed location. But if a more complex sculpture composed of multiple masses is approached in the same way, then each of the major masses is a separate onion. A point on the surface of a given mass will move steadily closer to the center of that mass as layers are peeled away, but it will simultaneously be moving in any number of different directions with respect to the other masses. For example, pairs of points on two inward-facing surfaces will move away from each other while pairs of points on outward-facing surfaces of the same two masses will move towards each other. If the composition looks right in a rough stage, the masses will prove to be much too far apart in the more finished stages.

Complex compositions thus invert the concerns of the sculptor: it is points on the surface, not overall masses, that must be defined first, because if two masses are to be in contact in the finished piece, they, not the way the piece as a whole evolves, must define the locations in space of the rest of the masses. A similar principle applies to surface detail. The sculptor cannot first get the overall design in place, and then apply the surface detai because sufficient stone must be left in place to completely cover anything that sticks out above the overall surface.

It is exactly the opposite of what a painter of draftsman does. Artists in two dimensional media always first try to get the masses blocked in, defer the surface details until after the masses are correct.

It is the need to work out the precise relationships of interacting masses in advance, not the copying per-se, that makes complex compositions in stone qualitatively different from monolithic compositions. Whether or not to use clay to work everything out in advance is sometimes treated almost as a moral issue, as if the artist who works in clay were somehow cheating, but the requirement for precise pre–planning of complex work is actually inherent, and can only be avoided by not making complex compositions.

Even if a hypothetical sculptor had the superhuman ability to imagine all of the finished surfaces of a piece within the block perfectly, and cut down to those precise points free-hand, in an important sense, it would still only simulate direct carving, becqause the compositional decisions would still have been made in advance, and could not be said to evolve in stone in the way that an expressionist or abstract painting or drawing does on a two dimensional surface.

Michaelangelo's work is the culimination of a movement to revive Classical art, and within the constraints of that style, it has never been surpassed, but like Classical sculpture, it tends to be relatively monolithic and frontal. And much as the complex and fluid compositions of Hellenistic sculpture succeeded the Classical style, Michaelangelo was succeeded by generations that favored complex compositions intended to be seen from all angles. The complexity of these compositions made the use of precise clay models increasingly the rule, and the separation of the the central creative act from the actual carving became more commonplace, making stone carving aesthetically more like working in bronze.

The overwhelming movement of art towards expressionism, primitivism, and abstraction in early Twentieth Century, eliminated the tradition of complex figurative compositions, making direct carving once again the more natural way to carve, and other than a few schools, such as *École des Beaux-Arts* in Paris, that continued to emphasise classical techniques, the direct approach to stone has overwhelmingly dominated the practice and teaching of sculpture in stone since Modernism.

The practice of carving front to back arises naturally when complex compositions are to be carved without mechanical copying. Because the final locations of the masses are fixed by the points where the masses touch or come close to each other, it makes sense to identify such points, which are by definition on the finished surface, at the outset. With the artist working from front to back, the elements of the composition that are closest to the front are fully carved first, providing a continually expanding set of precise reference points that will not be lost as the carving progresses. Because the current layer being carved only eats into the sides as the finished portion of the carving emergest, the maximum area of drawing on the sides and back are preserved for as long as possible, and a given region of the drawing is hewen away only just before it is replaced with a permanent carved surface.

Front to back carving thus occupies a middle ground on the way to fully indirect carving, in that it relies upon finding and fixing the precise placement of points on the finished surface at the beginning. Dealing with finished surfaces at the outset inherently de–emphasizes the direct carver's use of the current state of the masses as a reference for the carving next state, but less so than the direct transfer of points a model to all sides of the piece.

Vasari[Vasari 07-2], in reference to Michelangelo, does not make it explicit, but he does mention another interesting reason for abandoning the direct carver's practice of working from all around. It is not unusual for flaws and inclusions to be hidden within a perfect–seeming block. To paraphrase Vasari, working from front to back keeps one's options for recovery from an unforeseen problem open for as long as possible. Yet another practical advantage not mentioned by Vasari, is that for complex carvings, say, the snakes and extended appendages in the The Laocoön group, the uncarved background serves as scaffolding for the pieces that would otherwise be unsupported during the carving and finishing.

For modern carvers, each approach has its aesthetic strengths. Direct carving is at its most practical with one artist per object because the essential creative act is concurrent with the execution. The results tend to express a stone-like solidity, at least in part because the design decisions are made on a pay–as–you–go basis, and the emergence of the carving from the process is consistent with relatively less formal modernism.

For better or for worse, indirect carving conduces to a very different sensibility in several ways. Most obviously, creating the composition in clay allows the artist to make carvings of a complexity that would be extraordinarily difficult for a direct carver, and to experiment with compositions, make changes, and even start over from scratch, at relatively little cost.

Indirect carving also also profoundly changes the economics of making sculpture. The output of direct carvers is severely limited, as is their ability to produce work quickly, because the creative act, for which the nominal artist is essential, takes as long as the carving. The division of labor made possible by indirect carving allows a successful artist to produce an enormously larger body of work. Moreover, it is not just the making of original work that is facilitated—the same techniques allow the production of multiples, diffusing the artist's work to a much larger audience, further fueling demand. For a sculptor, the use of indirect techniques thus becomes both the consequence of, and the path to, celebrity. Historically, this is not a minor effect—Bernini, Canova, Rodin, and many others who were the preeminent sculptors of their time, headed studios that employed numerous assistants apprentices, and collaborators, and produced numerous copies and versions of their most famous work.

Despite the intensity of our modern passion for direct carving, historically, all the way back to ancient Greece, it has been more typical for sculptors to regard the abstract form as the primary thing, and whether it is expressed in stone or bronze, as essentially incidental.

The Classical World

This is a placeholder for material extracted from Blumel, Adam, and Richter.

The Renaissance and Baroque

Michelangelo Buonarroti (1475-1546), the quintessential sculptor's sculptor, was famously of the direct carving camp. He planned meticulously, but usually carved with only a small bozzetto as his only guide[3]. It is no coincidence that Michelangelo was obsessed with both stone carving and Neoplatonism, which was then revolutionizing the intellectual life of the Renaissance. Platonism is concerned with the division between the reality of Forms, and the concrete world we are able to experience[4]. The art of the sculptor, as understood in the

[3] Although he occasionally made full-sized plaster models for planning purposes[Wittkower 91].

[4] Neoplatonism comes up frequently in the context of Renaissance sculpture, and particularly with reference to Michelangelo. Renaissance Neoplatonism is a fusion of several ancient

Renaissance[5], was the expression of pure form in the most tangible of media.

Michelangelo remains fascinating to every generation, in part because his search for the Forms behind reality is so explicit in his mature carving. His David, and the glittering surfaces of the Vatican Pietá are the work of his youth (both were completed before he was thirty) but his more mature work was quite different: craggier, frequently showing tool marks, especially the claw chisel, and often unfinished. It is deeply satisfying, especially to the modern eye, to be able to see the imprint of his struggle in the unfinished work. His last work, the Rondanini Pietá, which he continued to work on during the last week of his life, at the age of 88, is the ultimate expression of this. The piece is hacked from the ruins of an earlier, nearly finished version, leaving unfinished an attenuated, almost ghostly version of Mary holding the dead Jesus upright.

Both Michelangelo and Donatello worked primarily from small bozzetti, eschewing indirect techniques, but even in their day, this was was exceptional, and in Michelangelo's case, somewhat misleading.

Michelangelo carved without aid of measurement, but he famously had an uncanny ability to imagine shapes in space[6], and his approach to the block remains, to this day, highly unusual among direct carvers, although it was advocated by Hildebrand for somewhat different reasons (see Section 11.6.1). Working from front to back, Michelangelo often executed the carving fully, as he proceeded through the block, so that portions of the front were finished while much of the piece remained buried under untouched stone. Vasari describes

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derivatives of the teachings of Plato (c.429-c.347 BCE) which had developed and persisted since the Fourth Century BCE. In 25 words or less, Plato taught that the material world we experience is only a transitory, imperfect approximation of Forms, the immaterial abstractions that are the immutable highest reality.

In a few more words, *The Allegory of the Cave,* given in *The Republic,* compares reality to flickering shadows on the wall of a dim cave, and Forms to that unseen thing behind us, that casts the shadows we see, but which itself can only be inferred by our ruder natures.

The Middle Platonist identification of the Forms with a single divinity accorded well with Christian theology, which subsequently incorporated a large dose of Neoplatonism when Saint Augustine systematized Christian theology in the Fourth Century CE. During the Middle Ages, the original texts were lost in the West, as was Greek itself as a scholarly language, and were almost entirely unknown until the reintroduction of Plato in Florence, in 1438. The reintroduction of Plato initiated an epochal resurgence of interest ancient Greek philosophy and art. Western thought, at the time inseparable from theology, was revolutionized by the wholesale re-introduction of fresh streams of Greek philosophy and culture.

[5] Renaissance sculptors venerated and emulated the sculpture of the ancient world, but Classical period sculptors would have been mystified by the Renaissance aesthetic. The still-persisting Western tradition of executing representational sculpture in bare, exposed stone originated in the Renaissance, not in the ancient world. To ancient sculptors, Renaissance work would have appeared strangely unfinished; the more exuberant Classical tradition elaborately polychromed most stone sculpture, and often heavily decorated it with accessories of bronze, gold, semi-precious stone, and other materials.

In the Classical Period, the painters of sculpture were as highly regarded and sought after as the sculptors themselves[Richter 70]. Also, because the stone was intended to be painted, the ancients also routinely assembled marble sculpture from multiple pieces, a practice that horrified Michelangelo

[6] Michelangelo said: "In every block of marble I see a statue as plain as though it stood before me, shaped and perfect in attitude and action. I have only to hew away the rough walls that imprison the lovely apparition to reveal it to the other eyes as mine see it."

this process, which he viewed first hand in his *Lives* [Vasari 07-2]. As detailed above, this is the direct carvers way of solving the problem of locating interrelating masses in space without direct measurument, and in this, Michelangelo was re-creating a process that had been used extensively by Hellenistic carvers.

It is interesting that in his latest, and in some ways most passionate work, his process least resembles these Hellenistic-era practices, and becomes almost expressionistically direct, as in the Rondanini Pietá,cited above.

More typically, Renaissance sculptors favored full sized models copied with the aid of manual measurement, although they did not use precise mechanical pointing that came into use in more modern times.

Vasari describes the ordinary procedure for Renaissance sculptors in detail [Vasari 07-2], pp. 48. A Renaissance sculpture typically started as a small bozzetto, which was then enlarged to a full-size figure in clay reinforced with horse-hair or other fiber. The clay figure was first modelled naked, and the drapery applied on top, not as clay, but as real cloth, soaked in clay slip so that it would be rigid when dry. The full size figure was allowed to dry (the reason why fiber reinforcement was necessary,) then copied in stone using carpenter's squares to establish corresponding points between clay and stone[7]. The use of carpenters squares falls short of true indirect carving, and is more akin to what a painter does in visually measuring with his or her thumb.

Still others, for instance Gian Lorenzo Bernini (1598-1680), the premier sculptor of the Baroque period and the quintessential virtuoso, gloried in their own craftsmanship, but did not scruple to use indirect carving when the scale, complexity, market demand, or issues of positioning demanded it. Bernini's works are so numerous, and on such a scale, that the attribution of work to him can be a judgment call; works attributed to Bernini may be entirely by his hand, executed with the help of other master sculptors, or merely designed and supervised by him[8]. While Bernini himself seems not to have personally carved indirectly, and executed many of his most famous works single-handely, much of his work used a different kind of indirect carving. He often made precise, full sized models, and handed off large amounts of the work to assistants who, working from his model, blocked out the sculpture for him. He also often hired specialists to execute decorative detail, such as foliage and clothing.

The Neoclassical Era

Antonio Canova (1757-1822), like Michelangelo and Bernini before him, was a true virtuoso carver, who dominated sculpture in his time. He was among

[7] Leon Battista Alberti(1404-1472) describes a measuring machine for the mechanical transfer of a model to stone. Alberti's machine produced measurements in the form of a radial angle from a fixed line, a distance along the radius, and a vertical distance to the measured point. The system and machine has the virtue of being capable of enlargement and reduction, by adjusting the scale on the target machine [Alberti 72]

[8] No single person could produce more than a small fraction of Bernini's sculptural output unaided, and sculpture was only one of his many activities. Bernini also directed the art policy of the Papacy, was an master architect, a composer, a playwright, a prolific designer of theatrical stage sets, and an inventor of theatrical machinery.

the most famous and highly regarded artists of his time, without a doubt the most famous sculptor, and among the first artists to be truly a celebrity in the modern sense of the word. The epitome of the Neoclassical style, Canova's work is cold by modern standards, and easier to admire than to love, but his mastery of the medium is unquestioned. For a number of reasons, a great deal is known about how Canova worked. Not only have many of his plaster models been preserved, but his studio was open to the public, and numerous description of the master and his assistants at work have survived, along with detailed drawings of the process. In addition to this, his friend and colleague, the sculptor Johann Gottfried Schadow, who's work is very similar to Canova's, wrote a paper, "The Sculptor's Studio" in 1802, that detailed his working processes, and how several people worked together to execute a large piece.

Canova worked predominately indirectly, and made extensive use of assistants as his growing fame created a demand for his work that far exceedeed what any sculptor could produce alone. In addition to a huge output of new work, many of his most famous works were executed repeatedly, including *Psyche Revived by Cupid's Kiss*, *Perseus with the Head of Medusa*, and *The Three Graces.*

Hugh Honor's monograph on Canova's technique, *Canova's Studio Practice*, [Honor 72], describes how Canova's pieces were executed. The master himself conceived the designs, did the drawings, and personally executed the originals in clay. These originals were cast in plaster, and numerous small iron pins were inserted to mark the points to be transferred into the stone block during the copying process see Figure 11.6.1

The actual transfer was done using both copying frames and calipers. Identical frames were erected above the model and the block to be carved, and a plumb line was lowered from the copying frame above the model to determine the precise location in space of a specific pin on the model. The horizontal position of the point was given by the point of attachment of the line to the copying frame, and the vertical location was given by the length of the plumb line. The marble below the corresponding point on the frame mounted above the block was then carved away until the plumb bob just reached the surface. The precise point was then marked, and the carvers moved on to the next point.

The monograph gives a detailed acount of the creation of the three figures for the tomb of Pope Clement XIV, seen Figure 11.6.1, including how long each portion of the work took and how many workers were required. Canova spent approximately four months working on the clay models. Using three assistants, the carving of the figure of the Pope required 100 days of Canova's time, of which 45 were spent on the face and hands, while his assistants worked 192, 99, and 17 days on the the same piece.

Figure 11.6.1 shows a detail of one of Canova's plaster originals with the iron pins marking points to be transferred into the marble block. Note that the tip of the pin is the point transferred, not the base, in order to leave a layer of stone for the final carving. Honor's monograph is not explicit on the issue, and the period illustrations are not clear, but as only points that are on top surfaces can be reached with a plumb bob, the calipers were undoubtedly used to locate

Figure 11.12: Canova,"Tomb of Clement XIV", Marble, 1792, Basilica di San Pietro, Vatican.

Figure 11.13: Detail of Canova model for *Psyche Revived by Cupid's Kiss*,plaster, 1794, Metropolitan Museum of Art, New York. Note the iron pins.

points on the surfaces that could not be reached in this way. See Section 12.2 for details on how this is done.

Canova was a perfectionist regarding the finished surfaces, and apparently did the final carving and smoothing himself by candlelight, in order to control the direction of illumination, for a better understanding of the surfaces.

Critics have made much of Canova's use of indirection, with some claiming he did almost none of his own work. Honor's monograph convincingly debunks this view. Canova was apparently highly active in all phases of carving in his earlier career, but as he got older, and the demands on his time increased, the proportion of his own contribution in time to to each piece decreased.

The 19th and 20th Centuries

Adolph von Hildebrand's[9] 1893 *The Problem of Form,* though now little read, and to many modern readers, unreadable, was one of the most influential works of criticism relating to sculpture ever written, influencing generations of critics and sculptors who followed, even across the divide of the Modernist revolution. His own work had more in common with the coolness of the Neoclassicists of the previous generation than with the lushness favored by his contemporaries, but his true aim was to revive the serene, monolithic spirit of the sculpture of the Age of Pericles. Compared to Hildebrand's ideal, Neoclassicism seems almost froufrou.

It is a book about much more than sculpture, and is one of the first attempts to unify aesthetics, and psychology, and to show why the true arts are not imitative, but architectonic, constructing the aesthetic experience out the combination of sense and mind. The arguments are all directed toward the final chapter, in which the author, an ardent admirer of Michelangelo, makes the makes the case that the achievements of Classical sculpture could only be emulated by an artist who carries direct carving to an extreme.

While Hildebrand's passion for direct carving has remained the dominant orthodoxy ever since, a closer examination of his reasoning leads one to suspects that the book was more widly admired than read. Hildebrand believed that the human eye can only understand form as a series of two dimensional layers at increasing distances from the viewer, and that sculpture in the Classical world had developed from drawing (i.e., a single layer) by way of relief carving. In Hildebrand's view, the true nature of sculpture is an extension of the relief, even when in the round, and that like relief, it should be designed for a frontal view, and executed, literally, from the front, as Michelangelo had worked, layer by layer. The completed work emerges from the block, but the essence of the block continues to exist, and to be expressed, in the completed sculpture. He regarded the progression of sculpture since Michelangelo towards complex compositions designed in clay, to be seen from every angle, as antithetical to the Classical spirit, and believed that Michelangelo's ideosyncratic practice of carving from

[9] Born 1847, died 1921.

front to back was of critical importance[10] in emulating the spirit of Classical Greece.

Ironically, Hildebrand's contemporary, Auguste Rodin (1840-1917), who is generally acknowledged to be the greatest sculptor of his own time or since, is one of the artists of the late Nineteenth and Twentieth Centuries who cared least about drawing distinctions between modeling and carving. Profoundly non-intellectual, Rodin certainly *could* carve, but he was a dedicated modeler, who almost always worked in clay or wax. Just as he would leave bronze casting to specialists, he typically left the execution of his work in stone to highly skilled assistants, albeit, assistants working in his studio, under supervision.

Like the work of Michelangelo, Rodin's stone sculpture is often non–finito, and features visible tool marks and raw stone, but both are done in a contrived and essentially decorative way. The marks are are usually unrelated to the origin of the forms themselves, which were fully worked out in clay in advance, and the uncarved sections of stone are planned from the start.

Rodin loved clay, but was almost indifferent to the final medium the piece would be executed in, and sometimes had plaster originals executed both in bronze and in stone. *The Kiss*, one of his most exquisite works in marble, was originally intended for casting in bronze, and was also executed in plaster and terracotta before it was first carved in stone for exhibition in the *Salon de la Societe Nationale des Beaux-Arts* in 1898. The piece was subsequently carved in multiple versions, in several sizes, and cast repeatedly in bronze, both with and without the permission of the artist.

Even Henry Moore, arch-Modernist of the generation following Rodin, and devotee of direct carving for a quarter century, shifted to indirect carving in the 1950's, when demand for his work, and increases in the scale at which he wanted to work, made carving it all himself infeasible. This was not a case of a deep-dyed direct carver resorting to indirect carving for massive pieces—Moore became a true modeler, and started producing work in both stone and bronze, eventually coming to regard clay as merely a faster way to get the same ideas out. See *Lives of The Great 20th Century Artists*[Lucy-Smith].

The contest between direct and indirect is never on a level field, because an aesthetic commitment to direct carving is self limiting—an artist can carve but so much stone in one lifetime, and few artists are physically capable of executing a large piece unaided in a reasonable amount of time. Whatever its aesthetic merits, indirect techniques multiply the productivity of an artist almost without limit, and therefore have historically tended to come to relative prominence whenever demand is great.

[10] Regardless of the merits of a single frontal viewpoint, Hildebrand's understanding of how Classical sculptors actually worked is no longer tenable. It has been well estblished that Archaic Greek sculptors consistently worked from four sides of the block, and that this mode of carving apparently continued to be the norm throughout the Classical period. The back–to–front procedure advocated by Hldebrand ironically came to be used primarily during the Hellenistic period, when compositions departed from the Classical spirit, becoming more complex, and indirect carving became a standard practice.

11.7 Naturalism and Verisimilitude

Notwithstanding the persistent romanticization of the ancient Greeks that began in the Renaissance, since Michelangelo's time, there have been countless virtuoso carvers who could shape stone as skillfully as any carver of the Classical world.

The paradox of stone sculpture is that for the great sculptors, the actual carving, per se, has never been the hard part. As pure craft, carving can be learned, like stone masonry (a branch of which sculpture was considered to be, prior to the Renaissance) and a skilled carver, given a model to work from, can reproduce any form that is consistent with the properties of the stone. What ultimately makes sculpture an art, rather than one of the building trades, is the ability of the artist to comprehend and define the pure form. Some artists *have* chosen to define that form directly in stone, but far more have worked in clay, and in either case, it is impossible to distinguish a high quality copy from an original by the artist's hand.

Even a glance at figurative carving of the Seventeenth Century makes it clear that it has been a very long time since there has been anywhere farther to go in terms of the mechanics of carving; certainly, sculptors since Bernini could make stone do anything that stone can do. Yet, throughout history, naturalism—representing particular, individual people in a lifelike way—has rarely been a primary goal of sculptors. Rather, naturalism has traditionally been subordinated to the creation of imagery that would not be overpowered by the primal force of the medium.

In the Nineteenth Century, Neoclassicists such as Canova and Schadow carried stylization of faces to an extreme. The image of Perseus on the far left of the image in Figure 11.7 is a typical example, but all the way back to the Renaissance, we see a limit to the degree to which sculptors in stone pursued verisimilitude as a goal. Michelangelo's David seems breathtakingly vivid and alive, but the artist's rendering of David's body is quite exaggerated, and the face, as seen on the left Figure 11.7 is not remotely naturalistic—a living person who actually had such a face would be terrifying. His Vatican Pietá is similar: Mary would be a bizarre looking woman indeed, with a tiny head[11] enormously wide shoulders, and 65 inch hips, with about a foot of space between her thighs. Likewise the work of Bernini: St. Teresa, also shown in Figure 11.7, is a powerful image which seems almost to breathe with life, but the rendering is actually highly artificial—no living woman ever looked like St. Theresa. This kind of artificiality is not for want of skill—all three sculptors were masters of the craft who could carve anything they wanted to. Even the sculptors of the Eighteenth Century who carried naturalism the furthest, retained a stylistic artificiality that imposed a distance between the representation and the human form.

There is a conflicting critical literature on why this is so consistently true, and undoubtedly the reasons vary to some extent from era to era, but one key reason is that verisimilitude is only one of the problems facing a sculptor. A common thread running through much of the literature on sculpture is that

[11] A real woman's head is 1/2 the width of her shoulders, while Mary's is more like 1/3.

Figure 11.14: Michelangelo's *David (detail), 1504, Gian Lorenzo Bernini's* Extacy of St. Teresa(detail),1652, Antonio Canova's *Perseus (detail), 1801*

a figurative sculpture has multiple natures that the artist must reconcile. A statue is an image of something, but it is also an object itself that takes up physical space, and is made of a material which has its own powerful presence in a way that a canvas does not. Stone is almost the opposite of the flesh that it portrays: cold, and hard, indifferent to time. Its association with architecture and its permanence make it a natural attribute of power; emperors do not declare their status with watercolors. Reconciling the image with the density and physical presence of the material is a fundamental problem that sculptors have always had to deal with.

In the Nineteenth Century, starting with a few sculptors who are nominally Neoclassicists, such as Houdon and Chantrey, a new kind of naturalism began to appear that was very different from traditional carving—a handling of stone that produced not just an image, but the illusion of life. Aesthetically, this is almost a magic trick, like a perfumer compounding a delicate scent from musk.

This kind of naturalism in three dimensions is a mysterious thing. Superficially, it appears to be like photography, but it is not, for no true three–dimensional analogy of photography exists for living things. The mental machinery for interpreting the two dimensional projection of the world on our retina allows us to interpret photographs and paintings even though they are in no way realistic. Little boys, like the one shown in Figure 11.7 do not have heads that are nearly as wide as their shoulders, yet the image is perfectly convincing. The closest thing to a photograph in three dimensions is a plaster life casting, yet though a casting may reproduce the shape of human features perfectly, the casting invariably looks physically shrunken and dead, and painting the plaster does not diminish the effect. For one thing, there is no such thing as "flesh tone" paint, because skin does not have "a" color, but is translucent, with even a single square centimeter of it showing not only countless colors,

Figure 11.15: Duane Hanson's *Man With a Camera (detail), 1991, Edward Onslow Ford's* Study of a Head(detail) 1885, Real little boy (detail), 2013

but many other effects of light that have only scientific names, such as sub–surface light scattering. Other features do not have mass at all in the way that flesh does: the eyes have numerous non–massive attributes like color, sparkle, transparency, and moisture; hair, unless heavily oiled, does not approximate a solid. Equally importantly, thought we are seldom aware of it, our bodies are in constant motion, although we become acutely aware of it only in its absence: the utter stillness of death can not be mistaken for life.

A naturalistic sculptural representation of a living thing must somehow compensate for all the absent attributes of life, by systematic distortions to the physical shape. For this reason, a naturalistic sculpture can never be "accurate" in the sense that it has the precise physical form of the subject. We see the effect of the absence of such beneficial distortion in the work of contemporary artists such as Duane Hanson and Ron Mueck, who polychrome sculptures that are cast from life, or in Mueck's case, scaled up or down from life castings. Though incredibly carefully painted, these pieces have an eerie, uncanny air—they convince only momentarily, before the viewer is made uneasy, even revolted, by the monsterous exactness.

The practitioners of the new naturalism were mostly academics, because most serious sculptors of the time were from the academies, but the new style was quietly as revolutionary as the work of the modernists. Like modernism, it walked away from the ancient artificiality of sculpture and the formalisms of the canon, much as the Impressionists had stepped away from the artificiality of academic painting, and painted what the eye actually sees. No exact analog of the Impressionist project can exist in three dimesions, because sculpture is an object as well as an image, but the practitioners of the new naturalism were attempting something similar: the representation of the true human figure, rather than an idealized construct conforming to a formal canon of proportion.

The members of the New Sculpture movement in England, and in parallel

Figure 11.16: *Mask of Pavlova 1924, wax,* Pavlova, marble, 1925, both by Malvina Hoffman

movements in Germany, and elsewhere, now used real bodies where the academic tradition had used idealized or mythologized figures; it was as if living people of the present moment had been frozen in time and space. The formalism of sculpting mythological themes persisted, but the New Sculpture had none of the distancing that canonical perfection and classical themes had given Neoclassical and Academic work. While the subjects of the New Sculpture were often beautiful, they were vividly real people. The effect can still be subtly shocking a century later—without the coolness of stylization, it can be as if one has walked in on someone undressed.

The pair of portraits of the famous dancer Anna Pavlova, shown pictured in Figure 11.7 were made the American sculptor Malvina Hoffman. Pavlova was the a principal dance of both the Imperial Russian Ballet and the Ballets Russes of Sergei Diaghilev. Hoffman, who studied under Rodin, was a prolific sculptor in bronze, marble, and other media in the early Twentieth Century. Both portraits show Pavlova at about 44 years old. The piece on the right is a conventional marble, while the polychromed piece on the left is wax. The

wax piece is an unusual example of a successful portrait piece based on a life casting. As such, it may be regarded as the exception that proves the rule, in that part of its power lies in contrast between the vivid polychrome, and her closed eyes and the death–like quality of the wax. This impression is quietly reinforced by its portrayal of the artist at an age at which few dancers are still active (although Pavlova in fact was, until her untimly death from pneumonia six years later, just before her 50th birthday.)

The historical moment for this kind of naturalism in stone may have been unique—it still remains to be seen[12] whether there is a place in the contemporary world for it. There is an unfortunate tendency, at this stage in history, to dismiss Victorian culture as excessively sentimental and prim. The Victorian sensibility was indeed emotional; Freud was just getting started, and the pervasive modern pose of knowing irony about what we feel was not yet the mode. But while it is true that there was much silly sentimentality, Dickens, Thackeray, Hardy, Elliot, Yeats, Shaw, and the Brownings were all at work, too.

If we find Victorian culture prim, they would have found us both heartless and timid, immodest about sexuality, yet ignorant about love, and prissy about death. Victorian tastes in women's clothing[13] should tell us that the clicheé of the repressed Victorian is missing something major. The sculptural naturalism of these years springs from the same roots as modernism: an intense intellectual struggle by artists and critical thinkers discover what the meaning of sculpture would be in the new industrial culture that was then being born. But it would not have been possible without the Victorian capacity for emotion—you cannot look at people as long, or as closely, as these artists did, unless you love them, and our era lacks the Victorian capacity for love. Beautiful nudity in our time tends to be unrealistic, and realistic nudity ugly. The sculptors of the end of the Century portrayed the body as both achingly beautiful and completely real. We, far more than they, are unwilling to look at bodies as they really are.

The naturalism in nudes of this period makes a startling contrast with both Neoclassical Academic work, and with contemporary hyperrealism, two movements from which it is equally distant in time. Pictured in Figure 11.7 are a typical Neoclassical nude (Bertel Thorvaldsen) on the left, and a contemporary hyper-reaslist nude by Ron Mueck on the right. Between them is a naturalistic nude by Francis Derwent Wood, *Atalanta*, carved in 1907, that illustrates the third path of naturalism. Except for the pregnancy of the third model, the women have similar body types, but while the Neoclassical nude is beautiful, it is an idealization that does not aim to capture, but to override, the model's individuality. The image of the pregnant girl is extremely specific, in no way

[12] That so many took this path at all may have been an accident of history; In the closing years of the century, in France, Rodin became effectively a one-man alternative to mid-Century Classicism. In England, many of sculptors who formed the core of the New Sculpture movement were taught by Jules Dalou, who had been a prominent practitioner of the highly naturalistic style in France, until, in 1871, he was forced into exile in England for eight years, to avoid being jailed for political reasons. Dalou convinced his friend, the emminent realist Edouard Lantieri, to go with him, which to some extent abandoned the field to Rodin during the his critical early years.

[13] The combination of corset, wasp–waist, bustle, and no bra is quintessentially Victorian.

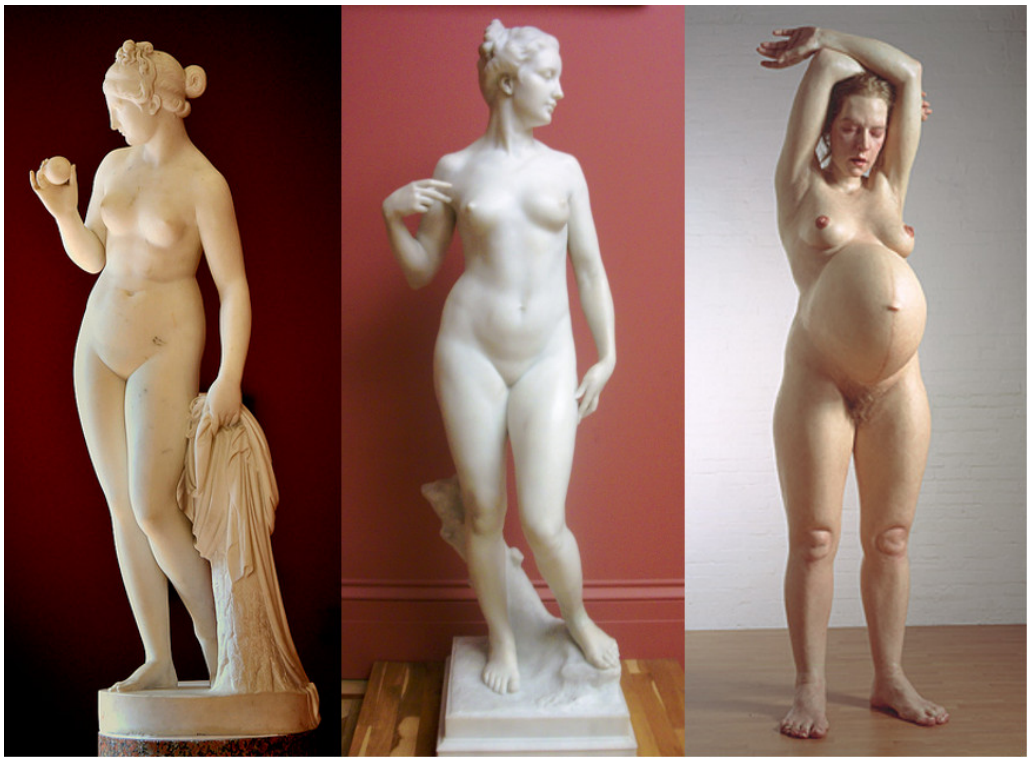

Figure 11.17: Thorvaldsen's *Venus With An Apple (marble), 1805, Francis Derwent Wood's* Atalanta (marble) 1897, Ron Mueck *Pregnant Girl (silicone etc.) 2002*

idealized, but her body, though cast from life, conveys no vital essence–it is just a piece of rubber shaped like a girl. In contrast to both, Atalata seems to capture life itself, while not giving up the immutability of stone. Note particularly the non–Classical proportions of her leg to body length, and the more realistic size of her head, as compared to the Venus, which is almost of action-figure proportions. Divergence from Classical proportions can also be seen in Atalanta's longer waist, larger hands and feet, and relatively heavier hips and thighs.

11.8 Viewpoints

Chapter 12

Indirect Techniques

Purely direct carving means attacking the stone directly, rather than mechanically copying a form that originates in some other medium, such as clay or wax. Indirect carving, the opposite, means copying into stone a shape that has been fully worked out in advance. Some sculptors are extremely direct, working without so much as a sketch, while others work entirely in clay, and may not even decide whether the finished piece will be stone or bronze until after the plaster casting is completed. The aesthetic issues around indirect carving are many, and are covered in Section 11.6.1. In this section we discuss practical techniques.

The basic problem solved by all indirect methods is that of measuring the location of a point on the surface of a model and transferring it to a corresponding point, either in empty space in the case of modeling, or to a point inside a stone block for carvers. Artists did, and still do, accomplish remarkable things with the traditional mechanical methods, but the old tools are now evolving rapidly because these measurements can now be done more far more quickly and accurately with lasers.

The techniques described below will probably remain in use by amateurs and artists for years to come, but professional and commercial carvers, and art restorers are already moving to laser measurement, and in some cases even to computer controlled machine tools driven by such data.

But the technology available in the fine arts studio is still considerable. Laser measuring tools for tradesmen, accurate to within a millimeter, are already available in the $50 to $100 range, can greatly enhance the pointing process as seen in section 12.4).

12.1 Copying Frame

Enlarging frames have been used since at least the Middle Ages to guide the sculptor in reproducing models, either in the same size or scaled. Frames are applicable to both relief sculpture and to sculpture in the round. Although

the technique is more often applied to modeling, it can be used with reductive sculpture as well. A stone sculptor would usually use the copying frame to enlarge a small original to a full-sized plaster model suitable for use with a pointing machine.

The basic idea is that similar rectilinear frames surround both the model and the space in which the reproduction will be executed, allowing points on the original to be located in three dimensions with X,Y,and Z coordinates. The same three measurements are then located on the frame surrounding the work piece. One great advantage of this system is that scaling is easy, because the frames can be made in different sizes, and ruled with proportional measurements. The following is an example of how the frame can be used.

- A ruled batten is clamped to two opposite top rails, parallel to the adjacent side.
- A plumb line is dropped from ruled batten to some feature of the model.
- The rules on the two rails give the X coordinate, the rule on the batten gives the Y coordinate, and the length of the plumb line gives the Z coordinate.
- When enlarging a model in clay, the same basic idea can be used to scale up the armature. Battens can be fastened on the sides and top, to allow supports to be clamped in a precise location to hold an armature while it is being attached.
- Battens locked into fixed positions can also be used as a location for "mother" points, from which precise locations can be determined using the three-compasses method (see below.)

The Metropolitan Museum, in New York has on display a late 18th Century example of a plaster model for *Cupid Reviving Psyche With a Kiss* (see Figure 12.1) by Antonio Canova, which was used to produce numerous instances in marble using the copying frame and plumb bob method. This piece is particularly interesting because still in place are numerous iron pins projecting from the surface to identify the precise locations of the reference points. The pins stick out from the surface approximately an eighth of an inch, and are very irregularly spaced, some regions having pins separated by only an inch or two, and other regions containing few or no pins. In general, more pins appear in complex areas, such as Cupid's hand on Psyche's breast.

Note that one can only locate positions on the top surfaces of the model in this way. Canova and his assistants supplemented the copying frame with calipers as described below. More about Canova's methods can be found in Section 11.6.1.

12.1.1 Alberti's Method

Giorgio Vasari describes a variation of this technique used by, or at least proposed by, Leone Battista Alberti, in the Fifteenth Century. Alberti's technique

Figure 12.1: Antonio Canova *Cupid and Psyche*, plaster, 1794, Metropolitan Museum of Art, New York (left) and detail of Cupid's right forearm (right).

uses one radial angles and two linear coordinates in place of the three Cartesian X, Y, and Z linear coordinates. In Alberti's method, a ruled radial arm is mounted in a fixed position above the model. A similar arm is mounted above the work piece. A plumb line is dropped from the arm to any chosen position in the space encompassed by the rotation of the arm. The combination of the angle of the arm, the point of attachment of the plumb line on the arm, and the length of the plumb line, uniquely defines any point in the space below, and can be transferred, at the same or different scale, to the corresponding apparatus above the target.

12.2 The Use of Three Compasses

It always takes three quantities to uniquely describe a point in space: copying frames use distances along three lines, and Alberti's method uses distances on two lines, plus a radial angle. The method of three compasses relies on the geometric principle that the location of any point is also uniquely determined by its distance from any three distinct points that are not on the same line. Note that for this statement to be true, you need to allow negative distances as well as positive.

In this method, three fixed reference points, called mother points, are marked on the model, as far apart from each other as is convenient. Three corresponding points are located in the target block in precisely corresponding positions Because the block is larger than the model, these points will almost always be on surfaces that have been cut into the block.

Given these starting points, any point on the model can be mapped to a point within the volume of the block, using three pairs of compasses. Putting aside for the moment the problem of transferring the first three points, the rest of the points are transferred from the model to the block using the following procedure.

- Three pairs of compasses, A, B, and C, are used, one for each mother point.
- The compasses have curved legs so they can reach around the model easily, and a wing-screw to lock the legs in positions after a measurement is taken.
- The point on the model to transfer is marked with a dot.
- After compass A is set to the precise distance from mother point A to the dot, one its feet is placed on mother-point A of the target block, and a small line marked on the stone where the swing of its other foot reaches closest to the approximate location of the target point in the stone. The procedure is repeated for compasses B and C.
- If all is set up correctly, the point we seek will be somewhere below the surface of the stone, within the region bounded by the three lines we have marked on the block.

- Some stone is chiseled away, and the three marks redrawn. The triangular region between the lines will be smaller than before, and the surface closer the point we are seeking. The divergence of the triangle from equilateral tells the carver how to adjust the angle of the plane from which the stone is being carved, so that will end up tangent to the final surface.

- As the triangle bounding the location converges to a single point, the depth of the target point below the surface goes to zero, and the target has been precisely located.

The only problem is, how do we find those three points on the target block? One of the ways this can be done follows:

- A rigid wooden frame is constructed that fits exactly around the target block on three sides. It should be snug, but easily removable.

- The model is fixed in position so it cannot move while the points are being determined.

- The frame is removed from the block, placed over the model and fastened down rigidly, but temporarily, in place.

- Points on the model are chosen at widely separated points that are will be reasonably close to the surface of the block, as indicated by the position of the wooden frame.

- A thick piece of wood with a 1/4" hole drilled through it is fastened to the frame in such a position that a 1/4" drill bit stuck through the hole will exactly touch the desired location of a mother point. The exact depth of the bit through the hole is marked, and the procedure repeated for the other three mother-points.

- The frame is now transferred back to the block, and the holes used to guide the drilling of holes to the precise measured depth, less say, 1/32". In most cases, it will be necessary to chisel the stone where the drill enters, so that it is exactly perpendicular to the direction of the drill bit. This prevents deflection of the bit as it enters the stone.

- After the holes are drilled, remove the frame, and chisel down almost to the bottom of the drill holes, leaving intact the slight dent made by the drill tip.

- Mathematically, only three points are strictly necessary, but you will want to drill more than three mother points so that there will always be a set of three at a convenient distance from the point to be transferred.

12.2.1 Alternate Method

The mother points do not actually have to be on the original model, so long as their locations with respect to the model are unchanging. A fixed frame constructed around the original can also serve as the location of the mother points, and may in fact be more convenient. If this technique is used, it is best to construct the frame so that the mother points can will all correspond to points inside the target block. If this is not done, an identical frame must also be constructed around the block and fastened to it, to prevent any relative motion between the block and frame.

In this way, the three compasses method and the copying frame method can be combined. The copying frame can be reserved for the coarse blocking out, and the three compasses used for the more exacting details.

12.3 Pointing Machines

Pointing is the most commonly used of the traditional techniques. The model is usually plaster, but wood or any other rigid material can be used.

A pointing machine is an adjustable armature attached to rigid frame, which rests, during use, either on three fixed points on the original, or on three corresponding points on the work-block.

The adjustable armature terminates with a steel or brass block drilled through to allow a long pin, like a knitting needle, to slide through. The armature is articulated with several degrees of freedom to allow the block to be positioned above any point on the model.

The adjustable pin can slide in and out freely. It is inserted so that it almost touches the stone, and a locking collar around it is tightened, so that it can be withdrawn and replaced later to exactly the same depth.

To take a point, the frame is mounted on the original, and the armature is adjusted so the pin will be perpendicular the desired point on the model. The pin is inserted until it almost touches the model, and the collar locked in position. After everything is tightened down, the pin is removed and the frame transferred to the work-block.

Before you start carving, you should be absolutely sure of two things: that the frame is in the same relative positions with respect to the model and the block, and that the finshed carving will be completely within the block.

If you have made the main members of the frame plumb and level on the model, they should be the same when the frame is on the block. If they are not the same, the piece will be carved at an angle. You can check this with small spirit level or a carpenter's square.

To be sure that the block will contain the piece fully, check the key, outermost points by setting up the armature and the pin, and checking that in each case, the pin bumps into stone when you try to replace it. If it does not, some of your points will be outside the block!

Figure 12.2: The pointing machine in place on a plaster model in-the-round.

There are two approaches to removing the stone that covers the reference point:

- Drill a hole in the indicated direction to the measured depth. The bottom of the hole is the desired point. Remove the frame and chisel away the waste stone down to the bottom of the hole.
- Estimate by eye the amount of stone to remove, withdraw the pin, or remove the entire frame, and use the point chisel, perhaps followed by the claw, to directly remove most of the waste stone. The pin may be replaced as removal progresses to check the amount being removed. This approach works best to remove a lot of stone on convex curves at the early stages of carving.

The number of points you will use to copy a piece depends upon the desired accuracy—a highly accurate copy can require thousands of points. To reduce the amount of work, a few key points should be chosen first so that the largest amount of stone can be removed quickly, leaving only a thin layer to go through to establish the final points.

Start with outermost spots where a tangent plane will not bump into any other parts of the finished sculpture, and set the armature well away from the piece–say, half an inch. Several points like this will let you strip off huge amount of stone, and greatly reduce the total depth you will have to cut through for the rest.

There is no need for drilling at this point. Pick the point that will put the maximum amount of stone outside the tangent line and start there. Use the punch to cut off all the excess, then move to the next point. when you have completed this stage you will have a shape that is as if you had stretched a covering over the original.

If there are large hollows that will not weaken any part of the piece, you can now proceed to rough them out. This is a good place to start using the drill, expecially if the hollows go all the way though. The hole gives you an indelible marker about how deeply you can chisel. Don't forget that in a hollow, the sides of the drilled hole can be the significant part, not just the bottom. If it's a through–hole, there won't even be a bottom.

Be careful to leave plenty of stone anywhere the piece narrows, such as the neck. In such a spot, you can either leave the entire area thicker, or you can leave bridges of stone in a limited area.

When only a thin layer of stone—1/4 to 1/2 an inch—is left, you are ready to start establishing the real points. You are going to choose points that divide the surface into little regions, like the triangles on a computer-graphics wireframe. Each of the little regions will be very close to flat. The size of these regions is a function of how accurate you want to be. If your points are to be, say, 1/16 of an inch from the finished surface, the curvature of one of these regions must be within 1/16 of an inch of being flat. Therefore, for big gently curving surfaces, the regions can be bigger, and for more tightly curving surfaces, the regions must be smaller.

You want all your points exactly the same distance from the finished surface. Cut a small measuring thickness guage that from a piece of material that is the exact thickness of the distance you want for your points, in this case, 1/16 inch. Plastic, brass, etc. are good for this. It should have a narrow end and a wider end, and be long enough for convenience—say, six inches long, an inch wide at one end, and a quarter inch at the other. Each time you take a point, you will slide this guage between the pin and the surface, so that your points will stand off the model by a uniform amount.

To mark a point, first set the pointer from the model with the spacer in place. Then transfer the frame to the roughed out carving, and reinsert the pin. Use a chisel to shave away the patch of stone until the pin slides in to within at most 1/8. Then mark the spot with a pencil and carefully drill until the pin inserts exactly. This point will be exactly correct, minus the thickness of your gauge.

You can now shave most of the 1/8 inch away, just leaving a small amount above the marking hold.

If you are working to within 1/16, when you have all the points drilled, you will only have about 3/32 of an inch of stone left, with the holes down to 1/16 of perfect. At this point, the rest is done by eye. Shave the stone away over each little region until you reach the bottom of the holes, leaving only the pencil mark, so you can shave away the adjacent regions.

When you are down to this level, there should be nothing left but rasping and other final finishing work.

Working to 1/16 inch would actually be fairly crude. Sculptors frequently copy to an accuracy of 1/32 of an inch.

Note that the machine pictured here is quite heavy for a sculpture of this size. Most machines are of lighter construction. This particular machine is unusually heavily built. This is because it is designed to allow a drill bit to be substituted for the pointer. The armature itself then serves as a drilling guide, to accelerate the roughing out stage as described above. When used this way, the drill bit is inserted into drill after the frame is placed on the block, and the hole drilled to the correct depth in one step. This process is only for roughing out, and is not accurate enough for the finished holes. It is necessary to flatten the surface where the drill will enter the stone with a chisel, so that the bit does not tend to shift before it bites into the stone.

Considerations for Pointing Sculpture in the Round

So far, this description of the the pointing process has been described as taking place from one side of the original only, as if it were a relief. Theoretically, a single machine could reach every point all the way around, but in practice, multiple sets of mounting points, and often, multiple machines are used, both for convenience and to allow multiple carvers to work at the same time.

The primary reference points are used to defined any number of alternate sets of holes. Bolt heads for the alternate mounting points can be installed in any convenient positions on the model, and transferred to the block using the

pointing machine. As with the originals holes, these must be outside of the surface of the model. Leave 1/4" to 3/8" of stone above the bottom of the drilled holes, so there will be a stone for the frame's points to seat in. Because the secondary holes are fixed relative to the originals, there is no need to be concerned about getting the copying frame plumb and level.

For large work it is common practice to use a large machine to set up mount points for smaller smaller machines, to avoid having to shift an unwieldy machine frequently.

12.4 The Pointing Machine Updated

A typical laser measuring device for contractors costs between fifty and two hundred dollars, and is capable of measuring distances to within plus or minus one millimeter. This tolerance means that the average error is only about 1/32 of an inch, and worst case about twice that, which is pretty tight. Mounted on an auxiliary attachment to the pointing machine, this device can replace the need for the removable pointer, while allowing the armature to be far from the workpiece, leaving room to work without moving the machine.

Once the machine has been adjusted to place the laser dot on the desired location, the distance to the model noted, and the machine transferred to the block, the carver knows the precise amount of stone to remove from beneath the laser dot in order to reach the correct depth. By conservatively removing a little less, and iterating the procedure, it is possible to quickly converge on a perfect depth with chisel alone.

Combined with the standard armature for areas where drilling is required, this can greatly speed up the roughing out phase of carving. Make sure you have a heavily padded, but easily removed cover for the laser device to protect it while carving.

12.5 Computer Numeric Controld (CNC) Carving

Milling machines controlled by computer, called CNC milling machines, have been used extensively in industry for many years for machining complex shapes from metals and plastics. When used on metals and plastics these technologies are often called five–axis machining because of the number of points at which the arm holding the cutting head can be rotated. A YouTube search on this term is a good way to check out the state or the art. Since the 1980's, the same techniques have been extended to controlling tools for stone shaping. Such machines are available commercially, and can be used to reproduce an original to almost microscopic accuracy. Objects as small as a figurine, or twenty feet tall can be carved in this way.

Figure 12.5 shows a piece from the *Captives* series, by the artist Quayola[1],

[1] Davide Quayola, who usually goes by his last name alone, is an Italian artist who lives and

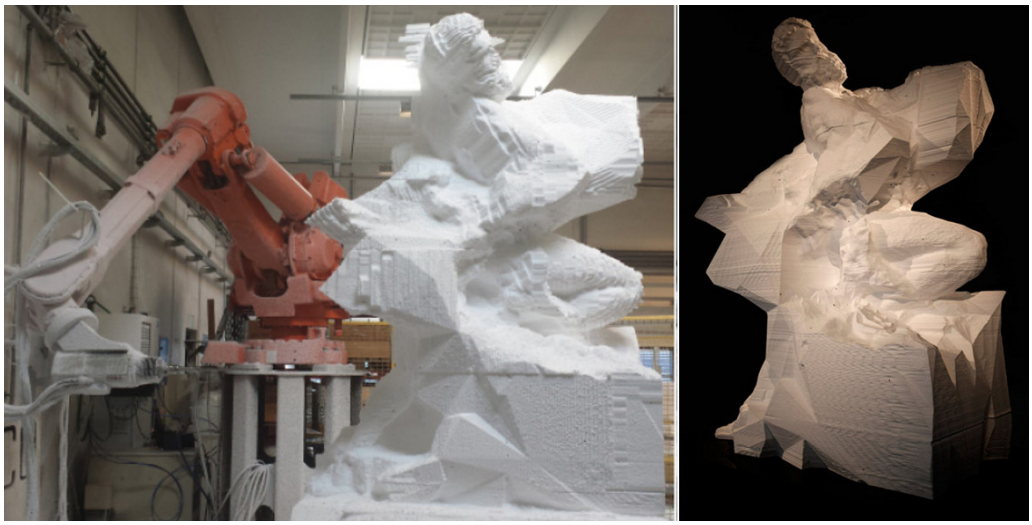

Figure 12.3: *Captives* 2012, EPS, by Quayola. CNC driven carving machine on the left, and the finished piece on the right.

being carved by a huge CNC carving machine. This piece is not actually stone, but high density expanded polystyrene (EPS) similar to the blue slabs used for insulation. However, the machinery and techniques used for CNC carving of stone are almost identical, except that with stone, a water hose is run continuously on cutting point to cool it and clear the waste.

The technology for defining complex three dimensional shapes as lists of number is fantastically advanced, and continues to evolve rapidly, in part because cinematic CGI and computer games use it extensively.

A set of numeric coordinates defining the surface of the piece to be shaped can be prepared in many different ways, but however the data is prepared, it consists of a set of locations on the surface, together with information defining how they are related. Usually, the numbers are represent the apexes of triangles as X,Y,Z coordinates. Triples of these coordinate points define a triangle in space, and the full set of triangles together define a wireframe model of the surface, but other systems can be used. The machine need not mindlessly carve out the triangles as flat planes—smooth curves can be interpolated even though the raw numbers actually define an angle.

One of the most common ways to get coordinates for an existing object is to use a laser scanner, either hand held or mounted on a tripod or scaffold. First, a few colored dots for reference points are stuck onto the original, for the sensor to use as fixed reference points. A laser beam, similar to the red beam of a bar–

works in London. He is not primarily a sculptor, let alone a traditional sculptor of stone. His work is more conceptual in nature, more often employing video and multimedia, and explores the relationship between information, the real, and the artificial, and frequently deals with the nature of originality and ideas in a digital context.

code reader, is played over the surface of the object being scanned, and the linear distances from the scanner to the reference points, and their angles with respect to the scanner are measured. These defined points providing a framework for computing the spatial locations of the innumerable surface points that will be the apexes on the wire frame, using the same trigonometry we all sit through in high school. The process is very fast and improves all the time. Not long ago, this process required rigid scaffolding for the scanner, but a modern hand–held scanner about the size of a highway patrol radar-gun works just as well.

The raw data is exported directly to a computer, where specialized programms turn it into models that can be used by the specialized Computer Aided Design (CAD) programs designed for CGI or other use. These programs can be used to manipulate the model in many ways, stretching, deforming, changing the surface texture, or even stitching multiple models together.

A CNC stone carving systems that use this data are scaled–up versions of CNC five–axis milling machines. They are basically a robot arm with a cutter on the end, and a sensor to tell exactly where in space the tool tip is. The computer intelligently plans the cuts, allowing it to grind away the surface in such a sequence that only the cutting head ever contacts stone.

Chapter 13

Building a Pointing Machine

You can build a much better pointing machine in the studio than you can buy commercially. The machine shown in Figure 13 is easy to make in the studio workshop. It is pictured being taking a measurement from a plaster model fixed to a plywood board. This is a common strategy for copying things that are small or fragile, or sometimes for originals, where making a plaster cast is not practical. Numerous measurements have already been taken, as can be seen from the pencil dots on the model. Note the pasteboard spacer, which insures that the pointer is always set to the same distance from the model, in this case, about 1/32 inch. (When removing the heavy overburden of stone, go down to roughly 1/4 inch first, and take points only at the high spots. This leaves only a small amount of stone to go through at the more exacting final pointing level.)

Most of the manufactured machines available are delicate, and can be used for measurement only. The studio-built machine described here will measure just as accurately as a manufactured machine, but has the advantage that it is tough enough to serve as a guide for a drill bit. This can be a tremendous time saver[1]. The machine is very simple and can be made entirely with a drill press and some hand tools.

The stock dimensions are not critical—the sizes for this machine were chosen because the steel happened to be available free. This example machine can handle bars big enough for life-sized or larger carvings, but larger or smaller machines may be scaled to suit your needs or to accommodate the available metal stock.

The long elements of the frame are five-eighths inch shaft stock. The joints are machined from one-and-one-quarter inch cold-rolled square bar stock. Cold–rolled refers to the process by which it is formed at the mill, which gives it a

[1] To do this, a long drill bit is used in place of the smooth pointer. After all but the last 1/8 inch of stone is chiselled away, the precision hole can be drilled using the pointer itself, without removing the frame from the work piece.

Figure 13.1: The pointing frame mounted on a board holding an original.

smooth finish that looks almost machined. You can substitute ordinary mild steel for either or both, but you will want to drill a test hole to be sure that you can match the bar stock to a drill bit. For big frames, using aluminum bars instead of steel would save a lot of weight. (You'd probably still want to use steel for the joint blocks.)

The mounting pins and the point are cut from three-eighths inch rod of unknown provenance.

The essential tools are a vice, drill press, hack-saw, carpenter's or machinist's try-square, taps and a tap-wrench, and drill bits to match the shaft stock. You will also need drill bit that match the taps. More on this below. Use high-speed steel drill bits for all the holes, not all-purpose carbide.

An electric grinder or a single-cut mill bastard file can be used to clean up and remove sharp edges. A reciprocal hack saw or cut-off saw is nice, but not necessary, for cutting hte bar stock.

13.0.1 Marking and Drilling the Connectors

There are three kinds of connector blocks used:

- The connectors for the main members have holes for two five-eighths inch bars drilled through adjacent sides of the block for joining bars at ninety degree angles. You need at four or five of these.

- The connectors for the three mounting pins are similar, but have one five-eights inch hole and one three-eights inch hole, again, at right angles in the block. You need exactly three.
- There is a unique terminating block for the armature that has two three-eights inch holes drilled at right angles, and one five-eights inch hole drilled in from the end. The big hole is for attaching the block to the armature. This is the block that holds the pointer.

The connector blocks are 2 1/8 inches long.2 1/8 inches long. You can do most of the drilling and tapping before sawing them to length.

Make a test cut with your hacksaw or cutoff saw to find out how big the saw kerf is. Use a try square and a scratch awl to inscribe cut lines all the way around the bar for each piece to be cut, allowing an extra amount for the saw kerf. If your saw kerf is 1/16th inch, the first piece will be 2 1/8, and the rest will be 1/16 longer.

The three blocks for the fixed pins that hold the frame to the model or the work piece are 1 3/4 inches long. The unique piece that holds the pointer is also 1 3/4.

The holes should all be marked along the center line, which should be scratched on two adjacent sides. They should be in from the ends 1/2 the diameter of the bar on one side of the line you will later saw (in this case, 5/8 inch). On the other side of the line, they should be 5/8 plus the width of the saw kerf, of course.

Using a machinists's punch, dimple each of the locations you've marked for the holes. To do this, place the tip of the punch precisely on your mark, and with the punch held perpendicularly to the steel, rap it once with a hammer. You don't have to hit it very hard. The dimple will center the drill bit when you start the holes—without the dimple, there's a tendency for the drill to walk around on the surface before biting in.

It will not be possible to mark for the holes to be drilled on the ends until the blocks have been cut apart, but for both safety and ease of working, it is best to do as much drilling as possible before actually cutting the blocks apart.

Drill five-eighths inch holes first. You must use a drill press for this. Do not drill pilot holes—go straight in with the full size drill. A word of warning: large drill-bits can easily fling the steel if you lose control of the work-piece.

Drill against a pine or plywood backing for two reasons: first, you need not worry about accidentally drilling into the drill press table if you don't have the drill centered over a hole in the table, and second, the undrilled dimples on the other side sink into the wood, rather than causing the bar to wobble. You can fix the wood to the table with two C clamps—these will stay in place until you are finished all the drilling. Clamp the work to the plywood table with another C clamp. Set the clamp up to hold the steel to the table loosely, start the hole (just touch the drill to the dimpled mark to ensure that it's in exactly the right position), then tighten the clamp to hold it in position.

Drill the holes for the tightening screws next. These will be used to lock the long bars into position. If you're using the recommended three-eights inch

screws, us a #16 high-speed steel drill, not a 3/8 bit—the #16 is specifically designed to leave enough steel to cut the threads from. If you have already made this mistake, simply go to the next larger tap size and the appropriate drill. My machine has holes are drilled on all sides for convenience—only one screw per bar is actually needed when tightening the armature.

When drilling steel, you want to keep the speed of decent of the drill constant, not the amount of pressure. If you merely apply uniform pressure, the drill will tend to suddenly bite too much steel as it pushes through the other side, and may either break, stop the drill press, or even fling the work-piece. At the very last moment of drilling through, you will be actually holding the drill back for an instant as it tries to pull ahead. This effect is more pronounced with larger drills, and worse when intersecting another hole, as we are doing here. To minimize this effect, drill the large holes first, then the small ones. Use drilling fluid or oil while drilling, and cool the steel in water after each hole or two. You can buy special oil for this purpose, but Three-In-One oil works fine, and even cooking oil will work. The oil keeps cuts down friction and dissipates heat so you don't de-temper the drill tip.

The holes in the terminating block of the armature should be 3/8, not #16, because they will not be threaded. Drill one in each direction to get full use from a block—the holes will wear eventually if used with a drill. You could even drill two in each direction, but they won't be on the center line.

Threading the Set Screw Holes

It's easiest to thread the holes before cutting the blocks apart. You can purchase at the hardware store individual taps and matched drills for threading the lock screw holes. If you opt for a different size set screw, make sure to get the matching tap and drill. For this design, it's a 3/8 inch tap and a #16 drill.

A tap-wrench is a T-shaped holder that fits a range of tap sizes. Lock the tap in the wrench, oil it lightly, and start screwing it into the hole as if you were opening a bottle of wine. Hold it as perfectly in line with the hole as possible.

You may feel it bind when some chips have been produced. When it binds, back off a quarter turn and twist again to let the chips fall free. Excessive force will break the tap.

When the hole is fully threaded, the tap should spin freely all the way in and out like a bolt. Oil is not necessary for cooling, but keeping the tap lightly oiled is helpful; too much oil tends to keep the metal chips in the hole.

Cutting the Blocks to Length

It's hard to get a square cut from one side using a hand-held hacksaw. To get square cuts, lock the bar in a vice and use a 24 teeth-per-inch hacksaw to cut a 1/16 inch deep slot on the first side, using your thumb to position the blade on the scratch line.

Use the first cut as a guide to start the second, and so on around the bar.

Figure 13.2: Cutting the threads with a tap and tap–wrench.

Using two shallow cuts act as guides, alternately cut at a low angle to each to get a perfectly square cut started on the corner. Once you've gone in a little way the cut will be self-guiding. Use long strokes.

With square cuts started on all corners, cut all the way through with the blade firmly held straight. Little pressure is necessary. Each cut takes about ten or fifteen minutes.

Alternatively, an iron works or machine shop may be willing to cut the bars apart for you with their stationary reciprocal hacksaw. Ask for a test cut first to ensure that the saw is well-adjusted. If it's sloppy, it can run out of square just like a hand saw. A stationary hacks saw will make a clean cut in less than a minute.

Clean up the rough surfaces left by the saw with a metal–grinding wheel on an angle grinder. Lock the work-piece in a vice and check often with a square to make sure you are keeping it square. Even a small amount of grinding will make it very hot—don't get burned.

When the piece is smooth on the face, make a quick pass on the edges at a forty-five degree angle to soften the edges and the corners. You can also do this with a file, a coarse sharpening stone or a sanding wheel on the angle grinder.

While the piece is in the vice, mark and dimple the hole to be drilled in the end, if any, for the second round of drilling and tapping.

Cutting the Long Pieces

Next, cut the five-eighths inch bars to length with the hacksaw. The lengths you choose are a function of the size of the pieces you anticipate executing. An eighteen inch length for the base, twenty four inches for the upright, and two or three pieces eight to twelve inches long for the arm should provide enough flexibility for a bust. You can always cut more as needed. Square them off neatly, and twirl them lightly against a grinding wheel to smooth and bevel the corner.

Cut a piece of three-eights inch stock about fourteen inches long for the top mounting pin. Put the bottom one inch in the steel vice and heat the steel an inch above the vice to cherry red with a propane torch. Keep the hot spot as narrow as possible by not moving the torch. When its glowing brightly, bend it over to a right angle and let it cool. Don't cool it in water until it is no longer glowing—you don't want to harden it.

Cut two equal length pieces of the three-eighths inch bar stock, about four inches long for the bottom mounting pins, and finish both ends of each square and neatly beveled using a stationary grinder.

Cut a piece about a foot long for the probe pin. Square one end, and sharpen the other end to a pencil-point with slightly softened end.

Details

You can buy ready made drill-stops that work perfectly for the locking collar, but they usually available only in sets, which include one for every size of masonry

drill. Alternatively, you can drill and tap a short section of bar stock, which is what is shown here. Drill and tap before cutting the stop off the main bar. A screw with a wing-head obviates the need for a screwdriver when setting it.

The end holes must still be drilled. Because of the small size of the workpiece, it is absolutely critical to lock them firmly in a vice, lest they be thrown by the drill. A wooden two–handled carpenters clamp is good for this. Clamp it to the table with a C clamp.

A Dremel-tool with a conical stone can be used to de-burr the outer edges of the holes. One light pass should be sufficient. Where holes intersect inside the blocks may also have burrs that interfere with the smooth sliding of the bars. Running the drill through them up and down should loosen them up.

If the bars don't slide easily enough in a block, chill the blocks ice cold, and re-drill with the press on low speed. Chilling shrinks the steel by a tiny amount, letting the drill take a few thousandths of an inch more metal, so when they return to room temperature, the holes will be a little bigger. Run the drill in and out of the hole a couple of times. This will polish the hole and enlarge it minutely. Blow the holes clean with compressed air, or clean them with a bottle brush.

Stiffness in the threaded holes will loosen up with use. When you're finished, spray everything with WD-40 and wipe clean with a piece of T shirt. The coating is for rust proofing, not lubrication. You won't want it slippery or greasy in use.

Notice that the pointer illustrated here is discolored on the pointed end. After grinding the point, it was heat treated to make it very hard. This allows the pointer to be tapped against the stone to mark the spot, and leave a small dimple to keep the drill from wandering.

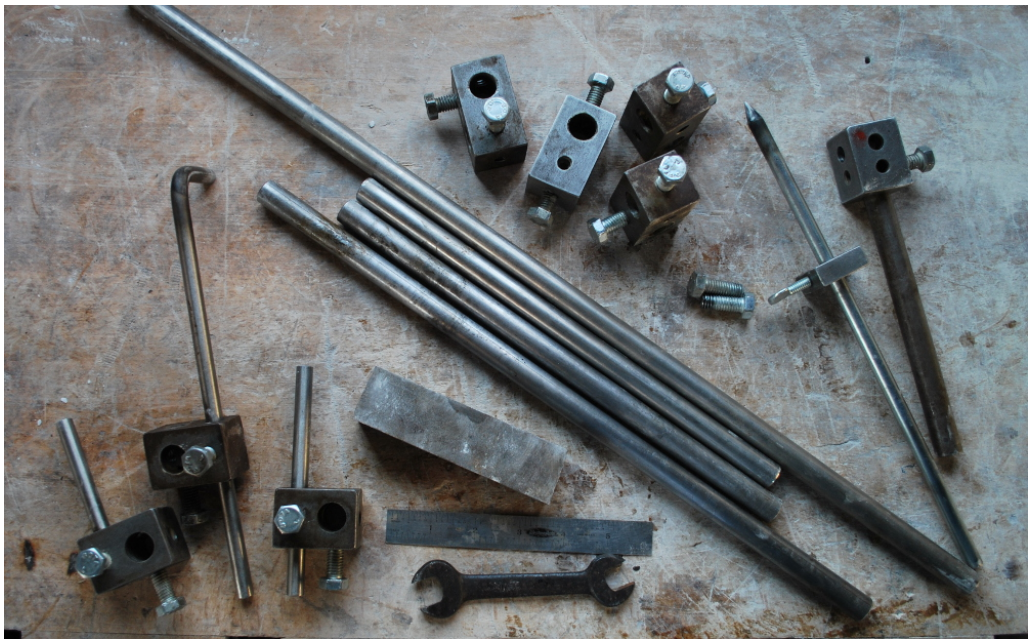

Figure 13.3: The full kit made from 100% from recycled junk, except for the machine screws.

Chapter 14

Making Tools

High quality sculptor's tools for marble and other softer stones can be made by hand. One good reason is to save money; another is to get exactly the tool you want. It's also fun and satisfying to do.

The first requirement for sculptor's tools is good steel. You can make a great looking tool from any kind of steel bar stock, but much of this kind of metal will be mild steel, intended for structural use. Mild steel is soft, and does not harden well with heat treatment. A better source of steel for new tools is old tools. You can pick up old mason's chisels and punches for next to nothing at flea-markets and garage sales.

Some of these can be tuned up and used as-is, or they can be reground without changing their basic shape. Others can treated as raw material to be forged into some new shape. One great source for heavier tools is worn out bits from pnumatic demolition hammers, which turn up a lot. These are hexagonal bars of high–quality steel, up to an inch thick, and often already forged into something close to a usable shape on one end, either a point, a chisel or a spade.

Flat pry-bars are a good source of high quality steel for smaller tools such as chisels and rodels. The steel is good and they are already the right thickness. Large screwdrivers can also be reworked into fine chisels and claws.

If you have some metal of unknown provenance, there are rules of thumb for evaluating it. If it rusts, it's some kind of ferrous metal, which is a good start. If a magnet will not stick to it well, it is not carbon steel, and probably won't work. The metal should get very hard when heat treated. You can test hardness by how easily it is scratched with a file, or dents when struck with a carbide punch. A quick test for high carbon content is to lock it in a vice and put an angle grinder to it with the lights low. Iron and low carbon steel will make relatively long straight sparks, while high carbon steel will tend to make sparks that break into a lot of branches. With old chisels, the mushrooming of the head can indicate the carbon content. Mild steel tends to roll over without breaking, while high carbon steel (good) separates into chunks as it mushrooms.

The following three concepts are necessary to understanding how to make

hardened steel sculpture tools.

Annealing: This is a process by which steel is softened, and the internal stresses caused by previous heating and cooling are relieved. Steel is annealed by heating it slowly, allowing it to remain at the desired temperature for a period of time, then cooling it slowly. Annealing makes it easy to work at room temperature.

Hardening: Medium to high carbon steel can be hardened by heat treatment. Somewhat simplified, the process for hardening carbon steel is to bring it to the critical hardening temperature, which is about 1375 degrees Farenheit, then cool it very quickly. At the correct temperature, steel will glow cherry red. What goes on inside the steel is complex, but in a nutshell, the quick chilling prevents large crystals from forming, leaving an internal structure of tiny, very hard, needle like crystals.

Tempering: The kind of hardening described above is all-or-nothing, and leaves the metal so hard that it is prone to shattering. To make the steel useable, the hardness must be tempered with another heat treatment. When the hardened steel is heated beyond a certain point (nothing close to cherry red) it will start to lose its hardness and become less prone to breaking. Once this critical temperature is reached, the higher the temperature, the softer the metal will get. The tempering starts at tempertures as low as 400 degrees.

Improvising a Forge

A forge can be improvised in the yard with bricks. The lining must be firebrick, as regular bricks will not stand the heat. If the brick is to be mortared together, it must be done with refractory mortar, because ordinary mortar can burst explosively when heated, as can any kind of concrete. Firebrick and refractory mortar can be obtained at any masonry supply house that sells supplies for fireplace building, or from a potter's supply house. An iron pipe laid in a gap in the brick can serve as a port for blown air. A hair dryer or heat gun can be used for a blower. A mixture of soft coal and charcoal will give a very high sustained heat. If a forge is too much of an investment, you can skip the whole thing and make do with a MAPP gas or acetylene torch, or even a large propane torch.

You will also need an anvil, heavy hammer, and tongs and gloves for handling the hot metal.

Making a Chisel

Assuming you have a steel bar, you can make it into a chisel as follows. First, anneal the stock. Steel begins to glow a barely-visible dull red at about 750 degrees Farenheit. At about 1375 degrees it reaches full cherry red. Beyond this is a brighter red, followed by a progression of colors: salmon, orange, yellow, white and incandescent white, you don't want to go beyond cherry red. If it gets too hot, the finished tool will be fragile no matter what you do later.

The tool should be placed in the coals and brought to a cherry red over a period of at least a half hour, and allowed to remain at this temperature for at

least another half hour. If the steel need only sawing, filing, and grinding, you can let it cool now. It should be allowed to cool as slowly as possible by moving it a little way out of the fire, but keeping it buried in the hot ashes.

If you want to forge a new shape, while the steel is still cherry red, it can be beaten into shape on an anvil with a two or three pound hammer. When hot, it can also be pierced and trimmed with chisels relatively easily. Keep it hot while working it, and when finished, let it cool slowly.

When the tool has cooled to room temperature, it is ready to work into to shape with any kind of metal working tools: files, saws, drills, cold chisel, or grinder.

The new tool will be uselessly soft. To harden it, heat the region to be hardened back to a full cherry red, allowed to remain at that color for a period of time, and then, abruptly quench it in cool salt water.

Don't just toss it in—immerse the front half of the tool fully, then quickly pull it out except for the tip, repeating several times, without ever fully withdrawing the tip from the water. The idea is to even out the temperature transition over a good length of the tool, so that the fully hardened region fades into the annealed region as gradually as possible. Sharp differences in cooling rate make the tool prone to breaking. The tool should not be allowed to cool in the water to below 200 degrees. When it approaches this temperature, allow it to air cool slowly.

The salt water can be prepared by mixing 3/4 pounds of rock salt in a gallon of water. The mix is not critical, and table salt will do just as well. Brine chills hot steel almost twice as fast as plain water because it boils at a higher temperature.

If the metal to be quenched is high-speed steel, stainless, or some other alloy steel, oil should be substituted for brine. Salt water can cool these metals so quickly that tiny internal cracks form, weaking the metal. Oil will not draw out the heat as quickly, reducing the tendency to crack. It also does not harden the metal as effectively, so there is a trade off that is particular to both the alloy and the type of coolant.

When the steel has fully cooled, touch it to the belt sander to clean the steel at the cutting end. Don't bear down on the sander, just touch it lightly, because you don't want to heat the steel at the tip. The idea is just to clean so you can see bare clean steel for the next step.

The steel will now be so hard that it is fragile. Tempering softens it to a controlled degree, making it much tougher. Softening occurs at much lower temperatures than the critical hardening temperature. The degree to which the steel is tempered depends upon the temperature to which the steel is raised at this step, but unlike hardening, it does not depend upon the abruptness of the cooling—only on the maximum temperature it reaches. The temperature to which the steel at the cutting tip of the tool is raised is estimated by watching the color changes on the clean surface of the steel. These surface color changes correspond to changes in the crystalline structure of the metal that occur at specific temperatures for a given alloy.

All the tempering changes occur at well below the minimum 750 degrees at which steel begins to glow a faint red. Note that the color changes associ-

ated with tempering have nothing to do with incandescence; the metal actually changes color, and it keeps the color after cooling. The progression moves from coolest to hottest with: pale yellow, straw, golden, brown, brown with purple, purple, dark blue, bright blue, and finally pale blue. The corresponding temperatures range from 425 to 610 degrees. At pale yellow, the steel will remain quite hard; at pale blue, most of the hardness will be gone.

One way to temper the steel in a controlled way is to apply heat well behind the tip with a MAPP gas, propane, or acetlyene torch. As the metal heats, the clean steel will start to discolor near the flame in the sequence above, and you can see bands of color move up the shaft towards the cooler tip as the metal heats. As soon as the desired colored band reaches the tip, instantly plunge the tip into cold water to freeze the temper at the desired level, then slowly insert the rest of the tool. It is necessary to keep the tip in the cold water, because heat will continue to migrate up the shaft of the tool from the heated section even after the source has been withdrawn, but you still want to cool the rest of the tool evenly, without abrupt changes in any one area.

Note that by this process, no part of the chisel ever reaches anywhere near the critical temperature for hardening—thus, there is no danger of re-hardening annealed areas; all it can do is soften the already hardened metal.

To reiterate, the tool tip will remain maximally hard up to about 435 degrees. Thereafter, the hotter the tip gets, the more it will be softened. The straw or gold for hard stones, and something closer to the blue range softer stones. The hardness depends on the alloy, as well as the temper, so trying the tools on stone will be the best guide to the appropriate hardness for your purpose.

Final Touches

When the tool has cooled to room temperature, do a final grinding, preferably with wet wheel. Just as tempering softened the steel by the deliberate application of heat, it is easy to ruin the tip by inadvertently heating it on a grinder. Grinding wet avoids this danger.

Electric powered wet grinders are great, but the inexpensive, manually cranked ones are fine for stone tools. They cut quickly, because unlike ordinary bench grinders, you can bear down continuously with no danger of burning the steel.

An Alternative Method of Tempering

Hardening and tempering can be accomplished together, with a single heating, as follows. The tool tip is heated to cherry red, just as in the hardening process described above. Then the last half inch or so of the tool tip is quenched in water for about three seconds, making it maximally hard. The exact time will depend upon the mass of the tool. The tool should be moved up and down in the water a little to spread the cooled region more smoothly, but keep the tip immersed for the whole three seconds.

The tool is then taken from the quenching bath and quickly rubbed on a block of stone to scrub a region of steel at the tip clean so that the color of the

bare steel can be observed. The mass of hot steel just up the shaft will quickly heat up the tip again, just as the application of the torch did in the preceding method. As before, when the desired color reaches the tip, quickly quench the tool to cool it, again, plunging the remainder in and out to smooth out the temperature transition.

This method works because the relatively large mass of steel behind the thinner cutting end can hold a lot of heat while still remaining well below the critical temperature for hardening. This method is easier to control on larger tools—small tools heat and cool quickly, narrowing the working margin.

14.1 Tools to Make

Claw Chisel Claw chisels can be cut from salvaged mason's chisels after they are anealled. Mason's chisels are ideal because they are fairly thin, but other kinds of chisels can be reground too. Anneal the chisels first, then clean up the end on a bench grinder to get it square and straight. Grind the sides to give it a long smooth bevel. Near the edge, increase the angle somewhat, so sides don't come together at too sharp an angle. There are many ways to shape the teeth, depending on what you want. A good way to get triangular teeth is to cut straight into the edge with a fine toothed hacksaw to separate the teeth, then finish them up with a knife file or triangular file. To get chisel–like teeth, you can also use a narrow warding file instead of a hacksaw to separate the teeth. A warding file is narrow, rectangular in cross section, and has cutting teeth on the edge, as well as both sides. They are made for cutting slots. The separation only needs to be about 1/8" deep.

When the tool is fully ground and finished, re-harden the steel and temper it to a level appropriate to the stone you intend to work with it.

Hand Sets and Heavy Chisels A decent hand set or trimming tool with a carbide edge can cost a couple of hundred dollars. If you're a stone mason, using it all day, it's worth the money, but these are just nice to haves for a sculptor. But you can make make heavy chisels of steel that work just as well as carbide on marble. Old bits from power demolition tools like pneumatic jack hammers are perfect. You can saw them down to size, anneal them, and regrind them into whatever chisel you want, then harden and temper them.

Regrind the edge to be flat and square.

Rasps and rifflers are made from tool steel blanks, annealed to be as soft as possible. Forge the blanks to a rough shape by heating and flattening them on the anvil as described above. The steel needs to be ground and sanded shiny smooth before the teeth are cut, or they will dull quickly.

Prepare a punch from a piece of good tool steel, such as a machinists punch. The shape of each tooth will be formed by the outer top shape of the punch. Carefully grind the end to a triangular cross section that will raise teeth in the desired shape when tapped into the soft metal at an oblique angle.

You must use a very precise touch to keep the teeth of even height. The teeth do not need to line up evenly. The punch gives them their final shape–nothing

further will be done to shape them.

Finally, harden the working end of the rasp as described above. Do not temper it, but try to get the temperature transition to the handle as smooth as possible.

Bush Hammer

To make your own bush hammer, anneal a suitable sized block of steel as described above. Old hammer heads can be converted, but test them for carbon content—Some hammers are made from low carbon steel that will not harden well enough. A piece of car or truck axel is probably a good candidate.

Cut the annealed block square on both ends with a hacksaw, and clean up both faces with an angle grinder and sander, testing with a try-square to make sure they are flat and square. Score cross hatching into the face to mark the divisions between the pyramids. Saw into the face along these lines to a suitable depth with the hacksaw, and then use a large coarse triangular file on the cut to turn the squares into little pyramids, which will all be the same height if the face was flat when you started.

When you've got it right, lock the block in a vice, and use a drill press to bore a large centered hole for the handle. Widen one end of the hole slightly using with a die grinder with a conical silicon carbide or aluminum oxide stone—either will work. Then harden the face as above, and temper it to very hard. A handle can be whittled fresh from hardwood or cut down from a broken hammer handle.

If you are really into it, you can make the hammer of ordinary mild steel, and then harden the teeth by a process known as "case hardening." This is a general term for various processes for soaking carbon directly into the metal to form a "case" of high-carbond steel around the tool. The case is only 1.0 to 1.5mm thick, so it is probably good only for hammers with smaller teeth. Consult blacksmithing resources for more details.

Chapter 15

Safety and Comfort

People go a little crazy about safety, in both directions. Some artists eschew all protection, relying on the fact that bad things only happen to other people. Other people bury them selves under protective gear, and go to work looking like they're on a Superfund cleanup crew.

Everyone does stupid things regularly, no matter how much experience they have. The amazing thing about workplace injuries is that practically everyone who gets hurt will freely admit later that they not only knew they were doing something stupid, but in fact were actually thinking about how stupid it was at the time of the accident. How much effort you want to put into safety is a personal choice, but the important thing to remember is that our intuition about how quickly slight risks add up is not good: we see that the the chance of getting hurt on any one occasion is very small, but forget that we're going to take that chance thousands of times.

Therefore, workplace safety has two parts: first, don't rely on your own good sense alone—you have to make safe practices something you do automatically without thinkng, like washing your hands in the bathroom. Second, be mindful—pay attention to that little voice telling you that you are doing something stupid.

If you are employing studio helpers, or allowing people to use your studio, safety is doubly important because of liability. Be sure you know what OSHA has to say about the equipment and processes you use if anyone other than you is involved. This goes double for young people in the studio. A lot of safety is using good sense, which mostly comes from experience, something that the young do not usually have a lot of. Don't assume people new to the studio understand basics—spell it out in detail.

15.1 Lungs

A respirator is highly advisable when working with marble and limestone, and absolutely essential when working with most other varieties of stone. Carving,

Figure 15.1: Worthless, good, best but maybe too much.

particularly with power tools, generates clouds fine dust that lingers in the air. Even if you wear a mask, ventilation is important too. Fine particles settle in still air at a rate of about a foot an hour in still air, so in an unventilated studio, the finest, dust can still be in the air the next day. Disposable paper "nuisance dust" masks, the kind with the rubber band, and the metal strip that pinches over the nose, are worthless, and do almost nothing other than giving you a false sense of protection. When you take one off, you can see thick white streaks around your nose where the air pours in around the edges of the mask. The thick fiber ones are better, but still pretty poor. For marble and limestone, choose a rigid plastic or metal mask with a soft rubber rim so it seals to your face, and replaceable cotton filters. Do not get the ones with the screw–in canisters, which are for chemicals and fumes, not dust.

The mask should pass the pressure test: seal the filters with Saran wrap and a rubber band, and inhale. There should be a vacuum against your face when you try to suck air. If there isn't, the mask isn't doing much. Note, sealing the filter with the palm of your hand is is not a good test, because you are squeezing it to your face more tightly than it would be in actual use. Replace the filters when it becomes noticeably harder to draw air through them.

A variety of filter types are available. For nuisance dust, like marble, you only need cotton unless you're extra sensitive. "HEPA" is the highest level of filtration. HEPA filters are more expensive, and although the higher level of filtration will not hurt, they are not considered necessary for carving marble and limestone which are chemically more or less the same as chalk. HEPA filters usually have layers of pre-filters in front of the HEPA-rated layer, to reduce unnecessary loading of the HEPA layer. Both layers have to be changed periodically.

If you are really fastidious, there are supplied-air masks that maintain positive air pressure inside the mask, eliminating all leakage, as well as the need for a perfect seal to the face. Clean air is continuously blown into the mask though a hose, so they don't depend on you sucking air through a filter, and unlike a regular mask, the intake is not right in front of the dust source, so the filters are

only filtering air that is already relatively clean. The masks that have one big plastic cover over your face are great—they don't encumber you, because they don't clamp onto your face, and the face shield obviates the need for glasses. Also, many kinds of masks direct your breath onto your face, which tends to fog your glasses, and these don't do that. The filtration unit and blower can be on a belt-pack, integrated with the mask, in a stationary unit or they can take their air from the compressor. The compressor fed masks are among the best, using high-quality filters that remove all particles down to 0.01 microns, oil and other contaminants. Sata is the best known brand for this kind of equipment.

The masks can be either full-face or just cover the mouth and nose. The down side is that they are very expensive—the full systems are in the $200 range for one person, and $1000 range for a multi user unit.

The tradeoff with dust masks is that the more effective they are, the more cumbersome. You can put up with a lot for a limited period when you're head down over the grinder, but will you actually wear it five minutes later, when the worst is over but there's still a lot of dust hanging in the air? You can't spend all day in the studio outfitted for an asbestos abatement project, so pick a mask that's protective, but that you will actually use.

Marble and limestone are almost pure calcium carbonate, the same substance as chalk, which is classified as non-toxic. You can eat the dust and breathe it without poisoning yourself, but it will still make your lungs ache. Granite and other hard-stone dust is not harmless—it's rich in silica and similar substances, and working it dry produces copious, finely powdered glassy dust. Sandstone, being composed mostly of silica sand, also produces silica dust. Long term exposure to fine silica dust causes silicosis, a very serious, chronic, degenerative, and incurable lung disease. It's not a good idea to carve silica-containing stones in a residence regardless of your ventilation system. If you do carve granite, or other stone containing silica or other glassy substnces, leave your work clothes in the studio to avoid bringing the dust home. Keep them separate and wash them all at once. Silica is harmless when it's wet and harmless to wash down the drain (powered silica is produced in nature by waves or running water causing gravel and stones to rub together.)

Other stone dusts can be irritating too. Talc, from soapstone, can be also be irritating in large concentrations, similarly to lime dusts, and requires similar protective measures.

Asbestos is a different order of hazard than the other stone dusts and should be avoided absolutely, for a number of reasons. In addition to causing asbestosis, a lung-scarring condition similar to silicosis, asbestos is also carcinogenic. Moreover, the dust can be exceedingly fine, far below the one-micron level, and not even HEPA filters get it all. Some varieties of soapstone, serpentine, and other commonly carved stones contain asbestos, so use them only if they come from quarries that guarantee the stone is asbestos free, or have it analyzed if you don't know where it comes from. (Asbestos is one of the serpentine mineral group, and is chemically identical to harmless varieties of serpentine, differing only in crystal structure.) Stone you buy at a sculpture supply house is usually ok—this caution applies more to stone you collect yourself, recover from

abandoned quarries, etc. The "green" in green marble is usually serpentine, and should be treated as suspect. If in doubt, grind a little dust and have it tested—asbestos analysis is easily available, due to the increasingly strict laws on asbestos abatement. Not only is stone containing asbestos impossible to carve safely in a studio environment, there are serious legal implications: by law, asbestos is a hazardous waste, so even cleaning it up requires a license, special equipment, and a certified hazardous waste landfill.

Be aware also that in some regions, there are stones that contain chemically poisonous metal ores such as lead, radium, arsenic, cadmium, uranium, and chromium, so if you intend to carve stone you have collected yourself, you should find out what it is first.

If you're a smoker, be fastidious about dust inhalation. Smoking multiplies the effect of lung irritants, because tobacco smoke temporarily suppresses the ability of the lungs to clear themselves. It's not just smoking while you are in the dusty studio—smoking at all is a problem, because the effect persists for several hours after smoking.

See the section on air cleaning.

15.1.1 Clean Air

Even if you use a dust mask, the workplace should be kept clean and ventilated. If you are using power tools on dry stone, the dust will be beyond the level where you can just put a fan in the window. A variety of dust collectors and ventilation options are available, but be aware that they aren't an automatic cure-all.

Portable dust collectors are vacuum cleaners with large-diameter hoses that put the collection head right at the work. The draw large volumes of air and do a good job of sucking up most of the dust at the source before it gets into the room air. Standard filter bags for collectors get dust particles down to one micron.

For table-top sized work, downdraft tables are excellent. These are workbenches that suck air away from you through perforations in the tabletop, directly into an air filter, away from the user's face.

Neither portable dust collectors nor downdraft tables get 100% of the dust, but they do a pretty good job.

Ambient air cleaners hang from the ceiling, and filter the main room air, and are intended to catch the dust that gets away from the portable collector. A typical studio-sized model cycles a volume of air the size of an average room every five minutes, through a one-micron filter. This is pretty good, but it doesn't mean the air is clean again five minutes after you stop grinding. They work more like a fish-tank filter, in that the cleaned air is continuously dumped back in with the dirty air. In practice, these filters will not fully clear the air of the particle sizes for which they are designed for at least an hour or so after the dust-generating activey has ended. Therfore, they are not to be relied on as the main air maintenance system.

You'll see the word micron a lot in connection with air filtering. A micron is

$$1/1000$$

of a millimeter, which is about

$$1/100$$

of the diameter of a hair. This is considerably smaller than can be seen with the naked eye, being at the larger end of the particle size range for smoke. Note that a one micron (abbreviated μ) filter is only moderately fine. HEPA filters, are rated to collect 99.97% of airborne dust down to 0.03 microns. The difference betwee 1.0 micron and 0.03 micron is approximately the size difference between a grape and a beach ball. Particles of 0.03 microns are in the mid-range for smoke particles, which can be as small as 0.01 microns. The very finest filters used for supplied air masks will catch particles down to the 0.01 micron size.

Unfortunately, it the smaller particles that are the worst for you. Dust that you can see, 5 microns and up, tends to be relatively harmless because the body easily catches it an expels it before it gets deeply into the lungs. Dust large enough to be visible also tends to fall out of the air much faster, and has less tendency to float around.

The bottom line is that it is not generally practical to keep studio air completely free of fine dust if the air is recirculated. The most effective solution is to use portable dust collectors get most of it, and also ventilate the room by exhausting the air to the outside. Even a small exhast fan will clear the room rapidly when the dust is not being recirculated. Ideally, the exhaust should be located so that as far as possible, the work is between the worker and the exhaust fan.

You will need to get the air clean enough that your exhaust fan does not constitute a nuisance, but this is not a very high standard and can usually be achieved with a portable dust collector. If the exhaust air is still too dusty, a filtering fan can be set up so that the exhaust air will be reasonably clean. Spray booth filters are good for this purpose, being designed for high volumes of fine dust. There are a number of video how-to's on how to do this available on YouTube.

Ambient air cleaners should be relied on only for keeping down minor dust levels when the weather is too cold for running the exhaust fan.

15.1.2 Eyes

You often find yourself spontaneously picking up a tool to do some little thing you just noticed. It's tempting to do the little task without putting on the glasses, and 99.9% of the time nothing will happen, but the little chances add up. Take two seconds and put on the safety glasses.

Chips of stone aren't the only thing that can fly around the studio. Steel tools can throw chips or sparks occasionally, even when carving soft stone. The chips can come from either end of the tool.

Disintegrating tool tips, cutting and grinding wheels, and wire-wheels can throw metal much harder than a chisel can throw stone, and they are less predictable.

Grinding stones can break up from centrifugal force. Metal burrs can break, or slip loose. If they do come loose, they don't necessarily just drop out spinning. The side pressure can cause them to come out crookedly, in which case the shaft can act like a throwing arm, slinging it to the side. This is one of the reasons you are not supposed to run die grinding tools in a power drill—drill chucks are not designed for vibrating bits or to take pressure from the side. When they do let go, they are more likely to sling the departing bit to the side, because they have jaws that the bit can get between. The collet on a grinder has no jaws, so it is less likely to sling a bit than a chuck.

15.1.3 Hands, Fingers, and Feet

Gloves protect you from scuffs and blisters, and they are some protection against getting cut, but they don't protect you from crush injuries, which are the biggest danger to hands. It's not just the hammer. You can crush fingers, hands, or feet anytime you are moving stone, by being pinched between two stones, or between a stone and the bench, wall, or floor, or by getting caught by winches, lifts, etc.

You always want to wear boots around stone, preferably boots with steel-toes. Steel toed boots give a lot of protection from moderate impacts and pinches, but they have limits. They mostly protect your toes, and only up to a point, but they are definitely a good thing.

The only real protection for the hands is to be alert, think, and take care when moving stone or metal. The most important thing is not to try brute force to move stones that are too heavy or unwieldy to fully control. A good rule of thumb is, if you even have to think about whether you're strong enough to do something, then you can easily get hurt doing it, not just from strain, but because you may not be able to maintain control. If it's too heavy, get help or use mechanical equipment.

It's not just dropping a stone; anytime a stone is in motion, it's dangerous. One common way to get pinched is when moving a block into a tight place, with a hand truck. You try to hold it back when setting it down, and get your hand pinched between the stone and the wall, or another stone. Don't use your hand here—use a piece of 2x4 at an angle to control it. Or set it down a foot away, then use a crowbar to inch it into place. Another very common way to get pinched is when walking a stone by rocking and twisting at the same time. You misjudge, and your hand gets slammed between the stone and the wall.

If you are going to do heavy work with a punch, consider using heavy duty mason's punches with the molded grip/hand-shield, instead of one of the punches sold for sculptors. They are cheap at the HomeDepot, and much more comfortable and safe to use, especially if you have big hands. If the taper isn't what you like for marble, just regrind them on the bench grinder.

Figure 15.2: Heavy duty mason's punch from Home Depot.

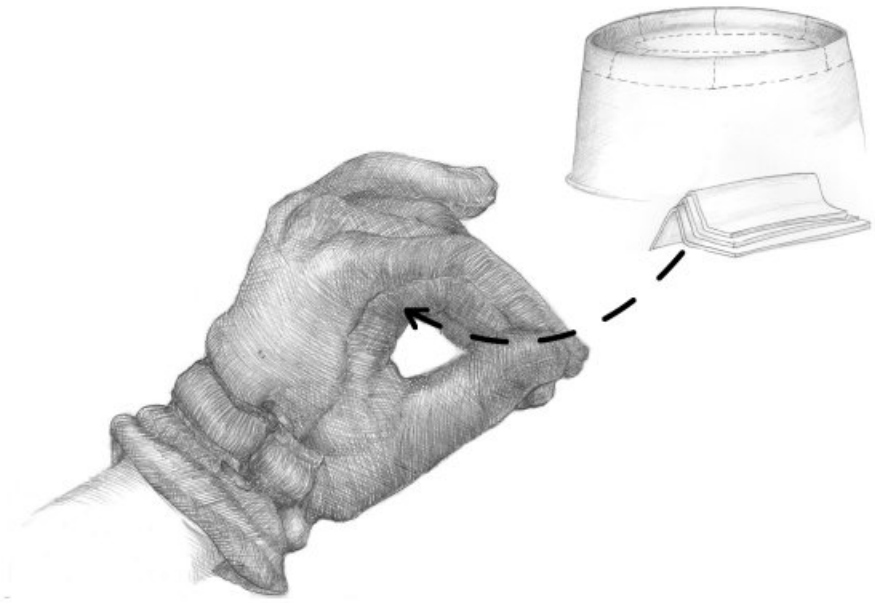

Figure 15.3: Tupperware knuckle protector—fasten with duct tape.

Better Gloves

For some reason, gloves are never padded on the one place it would be useful: the knuckle of the index finger, where the hammer hits you when it slips off the chisel. The second time really hurts. It's easy to armor your work gloves in this critical spot. Cut several one-and-a-half inch strips from the bottom corner of a round Tupperware container as shown in Figure 15.3. Leave half an inch of plastic on each side of the ridge. Two or three of these stacked up and duct-taped to the top of your glove over the knuckle will completely dissipate the force of a normal hammer strike. Wrap the duct tape all the way around the palm a couple of times. The tape will make the glove last longer, too. Do the wrapping with your hand almost closed in a fist, or it will be too tight.

15.1.4 Vibration Hazards

The use of vibrating tools can lead to a nasty condition known variously as "white fingers", "Vibration-Induced White Finger" (VWF), "dead fingers", and "dead hand." All these gruesome terms are synonyms for *Occupationally Induced Reynaud's Syndrome,* which is characterized by cold, bloodless, blanched-

looking fingers, accompanied by numbness and tingling of the digits. Medically, it's closely related to the response of your fingers to cold, and in fact, in some people, cold is enough to trigger Reynaud's syndrome. Early stages of this condition are characterized by numbness and/or tingling that persists for more than an hour or so after stopping work with the offending tool. If the condition appears, don't just tough it out—it is important to stop using vibrating tools, because the symptoms progress rapidly on continued exposure, and can lead to severe problems. Vibrating tools can also cause a number of more diffuse complaints known collectively as "vibration syndrome." Muscle weakness, pain in the shoulders and arms, as well as headache and depression have been linked to chronic exposure to vibration.

Susceptibility to vibration injuries is the luck of the draw—some people get them and some don't, for no obvious reason; being tough in other ways doesn't really affect succeptibility. If any of these symptoms appear, get the advice of doctor who is knowledgeable in the field of occupational health.

Vibration damping gloves are readily available at Home Depot, and are used by operators of chain saws and similar equipment. These gloves have special polymer pads that absorb vibration. Heavy users of vibrating tools should wear them to prevent problems. The condition is strongly affected by temperature, and individual susceptibility varies widely.

15.1.5 Grinders

The big hazards with bench grinders are flying debris, either from the workpiece or from the stone itself. This is particularly true if the rotational speed limits for the wheel are exceeded. The maximum speed for the wheel should be printed on it.

Store stones carefully, and don't let them bang into each other, or come in contact with concrete floors, etc. Anytime you change stones, check the stone visually for cracks, chips, and flaws, and do the tap–test, i.e., tap it lightly with something hard and listen for the tone. You can hear a crack in a grind stone, just as you can hear a cracked bowl or plate in the kichen. If the grind stone has a crack, not only should you not use it, you should break it up with a hammer so that it cannot be rescued from the trash. (The pieces can be useful for sharpening and other hand grinding.)

Stone wheels throw most sparks pretty predictably, so it is tempting to skip the safety glasses. Do so at your peril–they sparks don't always go straight, and they can bounce. They're glowing because they are on fire. You can often see tiny craters melted into your safety glasses after you have used the wheel for a while. They also go aound corners—regular glasses are better than nothing, but they aren't good enough—stuff still bounces in from the sides. The wires break off of wire wheels all the time, and they can get thrown hard enough to stick in your skin, let alone an eye.

Angle Grinders and Circular Saws

Angle grinders present all the hazards that bench grinders have, but with the additional possibility of winding your clothing into it, or bouncing it off the work and into yourself.

Clothing gets wound into them in a flash, and they can pull you in more powerfully than you can stop with your arm strength. Tuck everything in—hair, sleeves, etc., and don't wear jewelery, bandanas, etc. It's important to use them only when standing in a stable, comfortable position.

As with all power tools, click the trigger before plugging it in even if you are not holding it, to be sure that the trigger lock is not on.

15.1.6 Skin

Carving can be hard on the skin. Marble dust is alkaline, and extremely absorbant, and leaches the oil from the skin, pruning your skin, leaving your fingertips chronically looking like you just washed the dishes. It won't kill you, but expecially when combined with cold weather, it can lead to painful cracking that is slow to heal. Rinse the dust off your hands and apply lotion frequently. Vaseline Intensive Care is particularly good, because it leaves a waxy film. If you are particularly sensitive, use a liquid-gloves barrier cream.

15.1.7 Compressed Air Hazards

Air seems like a benign substance, but compressed, it is nothing to play around with–never let kids near it, and be sure anyone working in your studio knows what they are doing. A large proportion of commpressed air injuries are caused by practical jokes, and innocent fooling around.

Putting the air squirter in, or even close to, your mouth or other body orifice, can easily cause a fatal injury. Your body is only built to deal with pressure of a pound or two of air pressure. You can perforate a lung just blowing up balloons, and a compressed air line has a hundred times as much pressure.

Another common source of accidents resulting from playing with air is shooting things out of tubes, etc., using a blower handle.

The air hose is handy for blowing off dust and chips, clearing holes of debris, etc., but be very careful–the chips can fly hard.

The compressor itself can be a dangerous object, expecially if the drive belts and wheels are not fully covered, expecially because compressors turn themselves off and on automatically in response to tank pressure. Slow leaks can cause them to go on at any random moment. If you are going to work on it, unplug it—don't just turn it off.

Also, the energy of compression heats the air, making the compressor head extremely hot. The air intake (the small round hole in on the side of the air filter, on the extreme top left of the compressor shown) has high negative pressure, and will raise a bruise on your skin should you accidentally touch it when the

compressor is on. It would produce a very serious injury if a more delicate part of the body, such as an eye or ear, came close to it.

Hearing and Eyes

A lot of air tools are extremely loud, expecially the carving handles. You get used to it quickly, but it doesn't have to be alarmingly loud to be damaging, and air hammers get used for hours at a time. Seriously, use your ear protection when using air.

The other big hearing hazard is using a blower handle to squirt air on yourself to dust off. It is a very common practice, but it is considerably more dangerous than it looks—OSHA and industrial safety people warn against it. Still, most people in shops with compressed air routinely use it for this. If you do, beware that you can blow out an ear drum very easily, and it can drive particles into the eyes even at a distance. Both of these are common industrial and shop accidents. Be particularly careful blowing near waste from metal working tools such as drills and hacksaws, because the metal particles are dense and sharp, and hit with more force than stone dust.

Many air tools have powerful exhaust streams that produce the same kinds of hazards as manual blowers. It is a common practice to turn these tools backwards, and use the waste air to dust off the workpiece. If you do this, use appropriate caution—it's still a high–speed air stream.

15.1.8 It Seems Too Obvious to Say, But . . .

No power tool should be used when sitting—terrible things happen when they fall into your lap. They should never be used when you're in an awkward or uncomfortable position. Don't use anything more demanding than an electric drill on a ladder. If you have to use the heavy artillery up high, set up a proper scaffold.

A very common mishap is winding the clothes or hair into a drill, drill press, or angle grinder. It's amazingly easy to do and it's very sudden. Everything should be tucked in and secured, and never wear a necktie, bandana or necklace when operating any power tool.

Unplug the air or electric line when you change tools, and get in the habit of clicking the switch to disengage the lock-on button before plugging in any power tool. For stationary tools, unplug them before doing any work, including changing cutters. Don't use any damaged tool tip or wheel even if it seems to still work fine. If it cracked or chipped, it can easily crack further, and it's probably unbalanced as well.

That simultaneous use of beer and tools is widely recognized to be a bad idea.

Chapter 16

A Catalogue of Sculptors of Stone

The following is a partial listing of significant periods in the history of figurative stone sculpture, and some of the sculptors associated with them. This is a listing of artists who worked in stone, not of sculptors in general. Artists who worked exclusively in bronze or other media are mentioned only if they were also important to the history of stone sculpture.

By way of disclaimer, this list is ideosyncratic, and neither complete nor definitive. With regard to these periods, scholars frequently differ even on basics, such as the start and end dates, as well as characterizes the periods, and what they mean in the larger context of history.

There are a host of problems inherent in the very idea of classifying artists in this way. First, the customary periods do not all refer to the same kind of divisions: some are political divisions in a particular country, others are names of historical styles in a particular time and place, and some, such as Romanticism, describe both an era and an element of style that transcends eras. Moreover, artists are notoriously cooperative, and frequently ignore the categories that critics carefully lay out for them, freqently outliving their assigned era or working in an inappropriate style.

That said, these categories are better than nothing, and most of those mentioned below would be recognized by the majority of authors.

16.1 Under Construction: About 20 sections on significant eras in sculpture follow.

Chapter 17

Glossary

Acropolis: The name is formed from the Greek words for high and city, and unless qualified by some other place name, refers the the Acropolis of Athens. This is the rocky emminence where the temples to Athena are located, and is probably the most important single locus of Western cultural heritage. The temples were built in the Age of Pericles, replacing earlier generations of temples on the same ground, which were destroyed by the Persion invaders, who sacked Athens in 480 BCE. The Parthenon, the Erechtheion, the Propylaea, and the Temple of Athena Nike are all on this hilltop. The removal of the Elgin Marbles, now in England, from the Parthenon, played a large part in the cultural momentum of the Neoclassical movement. The ethics of their removal, called looting by many, and a rescue by others, has been hotly debated ever since. Many of the sculptures had been burned for lime by the modern Greeks, and War soon devastated the Acropolis, destroyed much more, so on balance, it has probably been a good thing, but the removal of the marbles has long been deeply resented by the Greeks.

Aluminum Oxide: A synthethic abrasive used in grindstones, both on bench grinders and on hand held grinders, and in coated abrasives (e.g., sandpaper.) Aluminum oxide stones are often pink, blue, light gray, or white. In the studio, aluminum oxide wheels are often used for sharpening steel, and both wheels and coated abrasives are used for grinding marble and other softer stones. The abrasive is not hard enough to grind carbide tools, granite, or similar hard stones.

Anisotropy: Not having the same physical properties in all directions. Slate, which splits more easily in one plane than in another, is a good example of an anisotropic material.

Archaic Period of Greece: The years from 750 to 500 BCE. The sculpture of this period, though often beautiful, has a rigid, stylized, unnatural look. Faces of Archaic sculpture often have a characteristic smile similar to smile seen on ships figureheads and outsider art.

Atalanta: In Greek Mythology, Atalanta was the daughter of King Iausus. Abandoned on a hillside at birth, she was rescued and raised by a she–bear.

Atalanta grew up to be a virgin huntress, priestess of Artemis, and heroine of numerous adventures with her hero peers. It was she drew first blood in the Caledonian Boar Hunt, and she was the only female Argonaut.

Baroque Period:

Basalt: A very hard, plain, grey stone, that can be polished to a glassy finish. Carved in ancient Egypt.

Bedding: The direction of the original layers of sediment in a sedimentary stone, or in a metamorphic stone, such as marble, that originated as a sedimentary stone. Stone cleaves more easily between these layers, so the bedding direction must always be considered when splitting a stone. A carver may also choose tools differently when working from one side of the stone or the other because of the bedding direction. The bedding is also significant when the weight of some projection, such as an extended arm arm, will apply significant torque to some part of the finished piece. See also rift.

Boucharde: See bush hammer.

Bozzetto: (Italian) A small model of a piece, usually wax, clay, or plaster, from which a sculptor works. The French word is *maquette*

Bronze: The name for numerous alloys of tin and copper. Bronze has been used since at least the third century BCE, for sculpture, weapons, tools, and other purposes.

Bronze Age: The historic period in which bronze was the most important metal for weapons and tools. The bracketing dates vary widely by region. In Greece, the Bronze Age is usually said to begin at around 2900 BCE, and end with the beginning of the Iron age at around 1200 BCE. Bronze was not abruptly eclipsed by iron, but was gradually supplanted by cheaper and more abundant iron. **Bruise:** Striking translucent stones, such as marble and alabaster, can leave a milky, relatively opaque region that extends down into the stone, anywere from a millimeter to a centimeter or more in marble, and considerably deeper in alabaster. This does not ordinarily apply to limestone, because it is already opaque, or to hard stones like granite. Bruising is also called "stunning," particularly in older usage.

Bush Hammer: A hammer with a textured face, often small pyramids, for pulverizing the surface of a stone. Also called a boucharde. When used on marble, it is sometimes called a frosting hammer.

Carbide: See tungsten carbide.

Carborundum: See silicon carbide.

Chryselephantine: Figurative sculpture constructed primarily of ivory and gold over a wooden frame. Often larger than life, they were frequently further decorated with glass, precious and semi-precious stones. The statues frequently served not only for worship, but as a component of the treasury, as much of the gold work was designed to be removed an melted down in times of hardship, to be replaced when finances allowed. In ancient Greece, chryselphantine was the artistic medium to which the greatest prestige attached.

Cinquecento: Short for the Italian millecinquecento, which means 1500. Note, this is equivalent to saying "the 1500's". The same period is otherwise called the Sixteenth Century.

Classical Period of Greece : refers to the years 480 to 336. This period begins with the defeat of the Persians by the unified Greeks led by Athens, and spear-headed by Sparta. It ends with the death of Alexander the Great.
Claw Chisel: A sculptor's chisel with multiple points instead of an edge. It is primarily used for cleaning up rough carving preparatory to finishing with an edged chisel, and occasionally as a finish tool, to leave a striated surface texture. Also called a tooth chisel.
Contrapposto: Italian for "counterpoise." This is the practice of modelling the figure in a pose characterised by an S curve. This gives a more dynamic and lively appearance. The introduction of contrapposto and similar dynamic poses is one of the chief innovations of the Classical Greek period. There is a striking contrast between the poses of this period and the static poses of the Archaic art. Occasionally it refers to the composition of multiple figures posed in reaction to each other. **Club Hammer:** A short handled hammer for sculptors. The head is just a rectangular block of iron.
Dating Conventions:

- **AD** is an abbreviation of the Latin Anno Domini, meaning "the year of the Lord." It is the traditional designation for dates since the nominal birth of Christ, but is now out of favor with scholars because of its implicit ethnocentricity.
- **BC** is an abbreviation of "before Christ." Like AD, it is now out of favor and has been replaced by BCE.
- **CE** is an abbreviation for "common era." Synonymous with AD.
- **BCE** An abbreviation for "before the common era." Synonymous with BC.
- **BP** is an abbreviation for "before present," with "present" meaning 1950. This is used in the context of radio-carbon dating, because the system was calibrated in 1950.
- **The Xth Century CE** is the century number following the century of the given date. E.g., Michaelangelo completed the Pietá in 1499 CE, which was the Fifteenth Century
- **The Xth Century BCE** is the century number one larger than the given date. E.g., the Greeks defeated the Persians at Plataea in 479 BCE, which was in the Fifth Century BCE.

Engineer's Hammer: A one handed sledgehammer, with a relatively long handle. Used primarily by tradesmen, but occasionally by sculptors.
Feather and Wedge: The combination of a steel wedge and two semi-cylindrical spacers that are used to split stone. Feather and wedge sets, inserted into a row of holes, can split stones of enormous size with relatively little effort. Wedges are sometimes used without feathers, particularly when splitting stones with a pronounced grain.

Felsic vs Mafic: See Mafic vs Felsic
Frosting hammer: See bush hammer.
Hellenistic Period of Greece : The years between the death of Alexander the Great in 323 BCE, and the annexation of Greece by the ascendant Romans in 146 BCE. The period is characterised by the widespread influence of mature Greek culture and thought throughout the Mediterranean, and the concurrent decline of Greece proper as the center of Greek culture. **Hyper-Realism:** Sculpture that is the three dimensional analog of Photorealist or Hyper-Realist painting. Realistically polychromed, and often cast from live models, these sculptures can be startlingly realistic.

Sculpture of this kind by anonymous artists has long been displayed in Madame Tussauds, but Duane Hanson and John De Andrea took it to a fine arts gallery setting beginning in the 1960's. Hanson's subjects are usually extremely ordinary people, clothed and accessorized in an ordinary way, while De Andrea's models are usually both beautiful and nude. Hanson and De Andrea use(d) polyester resins, plaster, and other conventional materials, as well as real hair. In the 21st Century, Ron Mueck, Evan Penny and others have used high-tech materials and techniques, including many developed for the special effects (FX) industry, to make astoundingly lifelike sculptures while playing with scale and distortion. The modern materials are far more lifelike primarily because the achieve more sophisticated effects of light than are possible with the older resins.

The amount Hype-Realist work done in fine arts by well known artists is dwarfed by the volume of work done to support FX. Special effects sculptors have carried the art of sculpting animals to a particularly extraordinary level, especially the convincing representation of dinosaurs and other prehistoric creatures, and imaginary beings.

The genre has always been limited by the very thing that makes it interesting. The contrast between the extraordinary verisimilitude of the pieces and the absence of life almost invariably produces a powerful feeling of the uncanny that dominates any other effect the work might have. Only a few artists have managed to avoid this problem, and in doing so they have not carried verisimilitude as far as the true Hyper-Realists. The sculpture of the Photorealists painter Audrey Flack, the one-off sculpture of Pavlova, done in the 1930's by Malvina Hoffman, and the early 20th C. work of Gilbert Bayes may point the way to a solution.
Intaglio: See Relief.
Inédit: An original model for a sculpture that has never been cast.
Iron Age: The historic period in which iron replaced bronze as the most important metal for weapons and tools. It is an imprecise term, and the bracketing dates vary by region. In Greece and the ancient Middle East, it is usually said to begin around 1200 BCE. The Iron Age in a given region is said to end not when iron ceases to be the dominant metal, but rather when historical sources replace archaeology as the the main source of our knowledge. Thus, the Greek Iron Age is usually regarded as ending in the Hellenistic period. Authors differ on precise dates even within a region, and sub-divide the period differently. One

useful distinction is between the Early Iron Age and the Middle Iron Age, which are distinguished by the availability of steel. In Greece, this division falls in the early Fifth or late Sixth Centuries BCE.

Lump Hammer: A short handled hammer used by tradesmen and sculptors. The iron head has two faces, and is similar to a club hammer, but has slightly tapered sides and smoothed corners.

Mafic vs Felsic: (Scientific) Mafic is a made up word describing a large class of igneous rocks composed primarily of magnesium (Ma) and iron (Fe). Basalt is a common mafic stone. The iron makes these rocks heavy, with a specific gravity greater than 3.0. Felsic, another made up word, describes the other large class of igneous rocks, which are composed primarily of silicon, oxygen, aluminum, and potassium. The "fel" is for feldspar, which is the silicon-rich main constituent. Felsic rocks generally have a specific gravity of less than 3.0.

Maquette: (French) See Bozzetto.

Monolith(ic): From the Latin *monolithus* meaning, consisting of a single stone. In archaeology, the word usually refers to a large, plain, stone monument, usually pillar like, sometimes of raw stone. As an adjective, in the context of stone sculpture, it is often used to describe a work in stone that emphasizes the massive quality of the original block.

Mycenaea: The capital city, 90 km south of Athens, of an early Greek people who dominated the region from about 1600 BCE to about 1100 BCE. Mycenae is famous for the massive stone ruins, and for the discovery, by Heinrich Schliemann, in 1876, of a trove of artifacts that included the gold Mask of Agamemnon (which may or may not be Agamemnon, and may or may not even be authentic.) Much of the mythology of the Greeks is thought to originate with the Mycenaeans. The only surviving example of monumental Mycenaean sculpture is the famous Lion Gate.

Non-finito: Non-finito refers to the practice of deliberately leaving a piece unfinished. The practice begain in the Renaissance, was famously used by Michelangelo, and has frequently been used since, notably by Rodin, but also by many others. Rodin's use of the technique often seems somewhat affected, as it tends to be used in pieces that are actually carved indirectly.

Perserschutt: German for "Persian dump," the Pereschutt is the ceremonial dumping ground on the Acropolis where the Athenians buried the sacred remains of the temples destroyed by the Persian army in 480. Bad luck for Athens was good luck for history, because this repository of sculpture and other artifacts was preserved for millenia, until it was excavated in the 19th Century, bringing to light many examples of Archaic and early Classical sculpture, including the Kritios Boy, and numerous Kouroi.

Phydias: 480–430 BC, was the the greatest of the Greek sculptors of the Classical period. No works still in existence can be attributed to Phydias with certainty, but numerous Roman and Hellenistic copies in marble exist. It is not known whether Phydias himself worked in marble; Plato claims that he did not.

Piccirilli Brothers: A commercial carving establishment in the Bronx, NY, which opened in 1888, and carved many of the great works of sculpture produced

in the United States at the end of the 19th and well into the 20th Century. Among the works produced by the Piccirillis were the sculpture of *Lincoln* in the Lincoln Memorial, *The Four Continents* at the Custom House in New York, The pediments, lions, and cornice figures on the New York Public Library at 42nd st., and the *Dupont Circle Fountain* in Washington DC.

Plastic Arts: The visual arts, as opposed to music, poetry, etc. The term traditionally refers to painting, and drawing, as well as sculpture, but is becoming somewhat ambiguous, as some authors now use it to refer only to three dimensional arts.

Ponderation: This refers to the nature of the planting of the figure's feet. Weight can be on one leg or both. The "engaged" leg is the one that bears the figure's weight, and the other is said to be "free." The the figure can be still or in motion.

Punch: A spike-shaped chisel used for roughing out stone. Also called a point chisel.

Quattrocento: Short for the Italian millequattrocento, which means 1400. Note, this is equivalent to saying "the 1400's". The same period is otherwise called the Fifteenth Century.

Relief: Sculpture in which the subject is carved leaving an attached back panel. The French term bas-relief is often used as a synonym for relief, but this properly means low relief, i.e., relief in the carving or modelling is shallow and does not employ undercuts. Relief may also be incised, meaning that the outlines of the figure are cut into the stone but the figures themselves are at the same level as the background. Traditionally, the Italian terminology distinguishes several degrees of relief:

- **Basso-relievo:** elements are only slightly lifted from the background.
- **Alto-relievo:** elements raised from the background half or more of their circumference. Some elements may be entirely in-the-round.
- **Mezzo-relievo** occupies the middle ground.
- **Intaglio** reliefs are carved in the negative, with the surface of the slab being the background, and the figures hollowed out.

Renaissance: The period of European cultural history following the late Middle Ages, roughly the Fourteenth to the Seventeenth Centuries, depending upon the region. The word is from the Old Frence for "to be born again." Sculpture in the Early Renaissance peaks with the later work of Donatello (1386—1466.) Sculpture in the High Renaissance, 1490—1527, is dominated by Michelangelo. The work of Giambologna epitiomizes sculpture of the late Renaissance (also known as Mannerism.) The Italian Renaissance ends around 1590, and is succeeded by the Baroque period.

Scarpellino : (Italian) A skilled professional carver who roughed-out sculpture for the nominal artist.

Seicento: Short for the Italian millequattrocento, which means 1600. Note, this is equivalent to saying "the 1600's". The same period is otherwise called the Seventeenth Century.
Silicon Carbide: An ultra-hard synthethic abrasive, invented in the 1880's. It is also known by the trade name Carborundum, and is the abrasive often found in green and dark grey grinding wheels, and in some coated abrasives. It cuts every hard material used by sculptors, in particular, it can be used on carbide tool tips, as well as granite and similar stones.
Stun: See bruise.
Rift: The direction in which an igneous rock cleaves most easily is called the rift direction. See also bedding.
Round Mallet or Hammer: A short handled sculptors hammer, with a tapered iron cylinder for a head.
Steel: Alloys of iron containing sufficient carbon to harden them, but not so much much as to make them fragile (e.g. cast iron) are called Steel. Steel may also contain small amounts of chromium, molybdenum, nickel or other metals, which modify its properties in various ways, but carbon is the key ingredient. Most steels can be softened and hardened using heat treatments, allowing them to be worked soft, then hardened for durability.
Trecento: Short for the Italian milletrecento, which means 1300. Note, this is equivalent to saying "the 1300's". The same period is otherwise called the Fourteenth Century.
Tungsten Carbide: An ultra-hard metal-like material used for cutting edges many power and hand tools. Tungsten carbide can cut any stone, wood, metal, or tool material used by sculptors with the exception of silicon carbide and diamond, which can be used to shape carbide tools. When a tool is called "carbide" it usually means that the tool is steel with a carbide cutting edge attached to it by braizing. Often, the carbide is set into a notch in the steel. Small carbide cutting burrs are sometimes ground from a single piece of carbide. "Structured carbide" refers to tools with irregular grains of tungsten carbide, rather than cutting edges. **Verism:** The name given to sculptural styles that show the true characteristics of the subject at a fine grain, especially signs of age, such as wrinkles, or a furrowed brow. It is used as a synonym for "warts and all," particularly when referring to ancient Roman sculpture, in which verism contrasts sharply with the idealization characteristic of the parallel Classical Greek tradition. Roman portrait scultptors often used verism to lend gravity or dignity to the portrayal of the subject, whereas the Greek tradition idealized the subject.

Beware that 20th and 21st Centuries Hyper-Realist sculpture is often referred to as Verist Sculpture regardless of whether the work of the artist is verist by the traditional meaning of the term. Verism and and a high degree of realism or naturalism may or may not occur together. For instance, grotesque and/or caricatured sculpture may be verist, but not realistic, while the work of the Hyper-Realist De Andrea is extremely realistic, but has an airbrushed Playboy centerfold quality that is almost the opposite of verism. The work of Duane Hanson may be regarded as both realist and verist.

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